An Organizational Planning and Feedback Control Model Incorporating Time-Span of Discretion

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AN ORGANIZATIONAL PLANNING AND FEEDBACK CONTROL MODEL INCORPORATING TIME-SPAN OF DISCRETION

Abstract

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A multilevel hierarchical planning and closed-loop control model is developed for the structure and general behavior of component organizational systems and the total organization. Elliott Jaques' time-span of discretion ideas and level of work estimators are conceptualized and formulated mathematically within the model framework. Based on such a systematic formulation as well as theoretical and empirical evaluations, it is concluded that the time-span of discretion concepts are highly significant system characteristics and the level of work estimators based on these concepts may be a valuable management tool in spite of certain theoretical limitations and practical problems. Although no mathematical modelling of the systems' dynamics is presently ventured, it is believed that certain quasi-linearity assumptions that would allow for the derivation and identification of impulse response and transfer function matrices are justified.

Initially, the model is formulated for the structure and general behavior of an arbitrary organizational level-ℓ subsystem whose composite operation is the direct responsibility of a level-ℓ role incumbent. The generally distinct effector operations of this system are in turn the direct responsibility of the level-ℓ role incumbent's subordinate down the chain of command to and including level-0 physical process opera-

tions. The output of the level-ℓ controller is, by means of lower-level "planners" and controllers, factored into goals and performance requirements for lower-level control systems. The typical data processing operation of data aggregation or compression found in any organization is modelled by "aggregators" through which the true performance of lower-level systems is passed prior to becoming feedback signals to higher-level controllers. It is because of the planner and aggregator elements that the nesting of individual control subsystems makes feasible the formulation of a hierarchical planning and feedback control model of the structure and general behavior of a total organization or some subsystem thereof.

With reference to such a level-ℓ component control system, the general nature of the feedback monitoring process is analyzed. A controller logic flow chart is proposed which incorporates effector adaptation, the iterative nature of planning and control as well as fast-time internal effector model response predictions based on the principle underlying the so-called Ziebolz automatic controllers.

A level-ℓ planning and control subsystem also serves as the basis for a systematic formulation of the basic concepts underlying the time-span of discretion theory. These concepts are shown to be directly related to such important system characteristics as the anticipation spans, the system's feedback sampling behavior and the way in which the system input is specified. Detailed time-span of discretion data are provided on the basis of interviews and field observations in two local firms.

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1. INTRODUCTION

1.1 The Systems Approach to Organizations

1.1.1 General Comments

Increasingly, researchers and practitioners are recognizing the potentialities of (general) systems theory as providing a major scheme of significance to organization theory and management: a unified approach to the analysis and synthesis of dynamics and structure of organizations and the management process. General systems theory itself, which is still in the formative stages, originated with and received its impetus from the work of such pioneers as von Bertalanffy, a theoretical biologist ([47], 1950); Boulding, an economist ([11,12], 1956); Rapoport, a mathematician ([39], 1956); Miller, a psychiatrist and psychologist ([35], 1955); and Ashby, a bacteriologist ([3], 1958). Its application to organization theory and management, which is of very recent origin, has become necessitated by the increasing complexity of organizations, the management function, and the interface between an organization and its environment.

General systems theory provides a basis for integrating knowledge from a variety of highly specialized fields since it claims to offer a unifying principle to science and a common ground for the study of interdisciplinary relationships of complex systems. It is this broad and at the same time unifying scientific base which makes general systems theory a potentially powerful approach to the study of organizations. Because of the realization that organization theory can be put in the context of general systems theory, a growing community of interest and understanding has resulted through the contribution of individuals from a wide diversity of disciplines. From a normative point of view, such a systems approach allows for and is increasingly being employed for the design of organizations that incorporate new and emerging managerial tools such as various quantitative methods, computer and information sciences and the behavioral sciences. It is argued that the systems approach to organization design is the only approach which is able to take full advantage of these managerial tools [53].

It is beyond the scope of this paper to present a review of the literature on the general systems approach to organizations. It has become quite voluminous during the years since Barnard [5], who was one of the early management writers to utilize the systems approach. Particularly the last decade since the introduction of the first textbooks on the subject (eg.[28,36]) has seen a high level of research activity and several reported applications of this "new" theory (see [50] for an annotated bibliography). Instead, we shall be primarily concerned with the "narrower" discipline of cybernetics, which is a more engineering-oriented sub-discipline of general systems theory, as it applies to the modelling of organization structure and behavior.

1.1.2 Organizational Cybernetic Models

The science of cybernetics since Wiener's classic work [49] has been a growing field of research and actual applications in engineering type problems. The application of cybernetics to organization theory, based on the central idea of self-regulation of goal-seeking systems by negative information feedback, is felt to hold a great deal of promise. In spite of fairly wide agreement on this point, "organizational cybernetics"* is still a subject in its early infancy. Although to say that organizational cybernetics is still at or slightly beyond the stage of Watt's steam-engine governor may be presumptuous, there is clearly a need to respond to the challenge of further developing such a discipline and to take more deliberate steps (rather than relying on accidental developments) to incorporate its concepts into the analysis and synthesis of organizations.

While numerous authors, including Beer [7,8], Simon [42], Miller and Starr [34], Optner [36], Young [53] and Strong and Smith [44] to mention only a few, have advocated and outlined organizational cybernetic models, these have generally been low-resolution single-level feedback control systems represented by schematic models or block diagrams. Very few mathematical models have been formulated for even these simple systems and the use of actual case data for such models is almost entirely lacking.

The first important mathematical model of a simple organizational cybernetic system appears to have been proposed by the late D.P. Campbell [13] in his analytic treatment of a production-inventory system. Through the complex-frequency domain approach to systems analysis and by assuming linearity of the various system elements, Campbell postu-

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*The term "management cybernetics" has been coined by Stafford Beer as being "the activity that applies the findings of fundamental cybernetics to the domain of management control" ([8], p. 144). Since the management control system is only a component of an organization's total control system, the term "organizational cybernetics" would perhaps be a more appropriate term for a general theory of organizations which emphesizes the science of cybernetics as its fundamental part. This term would incorporate "industrial cybernetics" [37] which refers to the control and instrumentation of the physical processes performed by the lowest-level systems within the total hierarchy of systems defined for some (industrial) organization.

lated the general form of the transfer functions for the system elements from which the form of the closed-loop transfer function matrix was derived. In particular, the effect of different production management policies or modes of control behavior on the total system performance was analyzed under certain assumed conditions. That is, alternative compensator dynamics were evaluated; the compensator portion of the controller being the decision unit that, in response to discrepancies between actual and desired inventory levels, determines the required production volume for components to enter inventory.

The same type of production-inventory problem was also considered by Simon [42] a few years later. Again, the modelling system was a basic servomechanism with a load on the effector or controlled element corresponding to the volume of customers' orders per unit time. Simon also presented a theoretical analysis of alternative production management decision rules and their effect on system performance. This pioneering work by Campbell and Simon, which were among the first efforts to illustrate the applicability of powerful and very general servomechanism techniques to industrial production type problems, has later been extended to incorporate such concepts as stochastic product demand and sampled-data systems analyzed via the Z-transformation (see, eg.,[18]). These promising quantitative ideas are still in their formative stages.

An early case study has been made by Haberstroh [23] of the safety system of a U.S. steel plant. The system was formulated as a control system in which top management control actions (considered as (i) intensity of response to injuries and (ii) level of independent safety activity; both being assumed to be constant parameters) were made in response to both the actual accumulated number of injuries and the error between this and the "desired" injury level. These control system input and output variables were considered at the total plant level and are thus aggregates of the same type of variables for individual shops.

Based on our own field studies, which include a major U.S. steel company, and also on Haberstroh's own description, his proposed model must clearly be only a partial model of the real safety system. In particular, several more control loops would appear to be needed at each organizational level as well as between different levels since various role incumbents (eg., shop foremen, general foremen, superintendents, etc.) are partly responsible for the safety control of their subordinate subsystems. Thus, a multilevel hierarchical model would seem to be more appropriate in this case. Furthermore, Haberstroh's model would seem to be incomplete without also considering that (i) the safety control system interacts with other systems such as production control systems and (ii) the safety control system variables are vector quantities accounting for differentiation of the injury attribute into types and degrees of injuries. However, in spite of its incompleteness, this study is still an interesting pioneer effort in applying the organizational cybernetic approach to the modelling of a given organization.

The work in "industrial dynamics" by Forrester [20] and his colleagues at MIT also falls essentially within the domain of organizational cybernetics. An industrial dynamics model, which typically possesses an elaborate network of information feedback loops, considers total organizations by integrating its several functional areas such as production, research, personnel, marketing, investment and accounting. By aggregating discrete events (eg., the shipping of a product, the placing of an order, the production of a unit, etc.), an industrial dynamics study is concerned typically with time-continuous systems. The causal relationships between pairs of system variables are usually in terms of linear differential equations with constant coefficients. The mathematical model of the total system is thus a set of differential equations. Based on such a model for some given organization, computer simulations rather than analytic techniques are used to evaluate system performance under alternative management policies.

One of the main objections to industrial dynamics and a major reason why it is not in more widespread use is that an industrial dynamics model, if it is to be realistic and useful, may become very complex involving hundreds or even thousands of variables. Relatively few firms have the type of computing facility necessary for handling such a problem. Furthermore, it is argued that before industrial dynamics can be successfully used as a management tool, "a great deal more has to be learned about the modeling of enterprises and the analysis of large scale feedback systems which are subject to stochastic inputs" ([18], p. 389).

1.1.3 Multilevel Hierarchical Model Structures

For an organizational cybernetic model at a resolution level that explicitly involves the operations performed by individual role incumbents, some sort of multilevel hierarchical model structure is clearly required. It is in fact argued that hierarchical structure "is not a characteristic that is peculiar to human organizations (but) is common to virtually all complex systems of which we have knowledge" ([43], pp. 40-42). However, a general theory of hierarchical systems within the framework of general systems theory is only now beginning to emerge.

The development of a theory of hierarchical systems is very much due to the work done by Mesarovic and his co-workers in the Systems Research Center of Case Western Reserve University (see, eg., [33] in which some of the work done by other researchers is also mentioned). Mesarovic et al. present a theory that proposes to cover any multilevel hierarchical system. They consider such a general system to consist of hierarchically arranged and interacting subsystems, which are typically decision (making) units, superimposed on a possibly composite physical process or production unit. Subsystem interactions are primarily assumed to occur directly between adjacent-level subsystems although the existence of more complex coupling patterns is not necessarily excluded. A typical schematic model of such a hierarchical system as considered by Mesarovic et al. for a level-3 system is illustrated in Fig. 1.

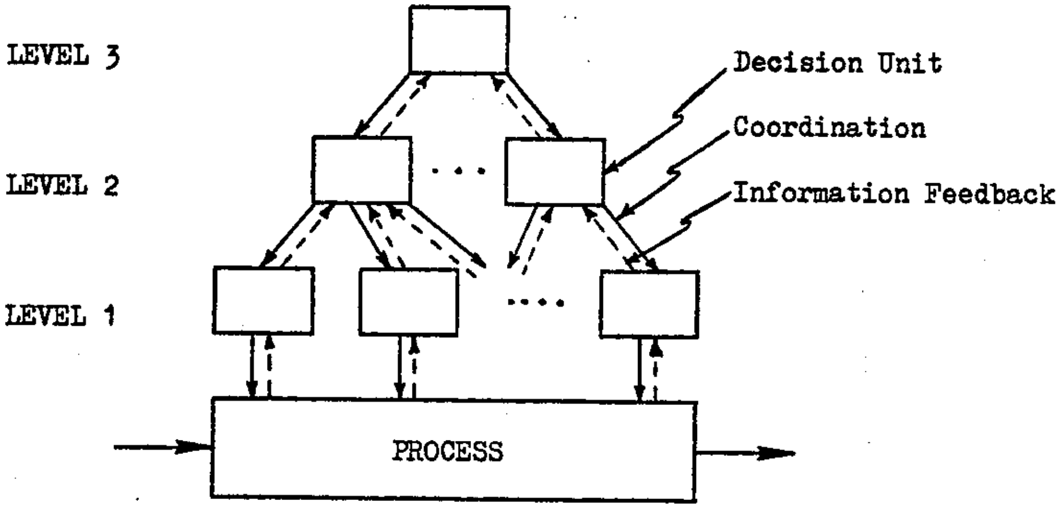

FIG. 1: LEVEL-3 HIERARCHICAL SYSTEM

The coordination inputs-outputs of this model are considered equivalent to what "is also referred to in organization theory as control (inputs-outputs)...(which)...divides (themselves) quite naturally into two parts:

the establishment of operating rules instructing the members of the organization how to act and the enforcement of these rules within the organization" ([33], p. 23). It is in terms of these "variables" that lower-level subsystems "are influenced or controlled by other (higher-level) decision units" ([33], p. 49). In turn, there is "dependence of the higher level subsystems upon actual performance of the lower levels" ([33], p. 34) as denoted by the dashed information feedback paths in Fig. 1. Of the above system characteristics, Mesarovic et al. are particularly concerned with coordination of which they have attempted to formulate a general mathematical theory.

Although we recognize the novelty and potential significance of this general multilevel hierarchical systems approach to organizations, a couple of points relating to the organizational system structure illustrated in Fig. 1 warrant some comments. In particular, we feel that the indicated information feedback loops are not generally the most significant ones among the set of all possible feedback loops. Thus, a level-ℓ subsystem (decision unit) would typically receive feedback information about the performance of level-$\ell'(<\ell-1)$ subsystems without such feedback necessarily going through intermediate subsystems. This would also apply to the level-0 (zero) systems or "process" in Fig.1 considering this process as being resolvable into distinct component processes. Although the highest-level (i.e., ℓ=L=3 in Fig. 1) subsystem is concerned with the performance of the level-0 subsystems, it is generally not as concerned with the detailed information about these systems output variables as are the level-1 subsystems or the level-2 subsystems for that matter. In terms of the schematic model in Fig. 1, we are then proposing that the feedback from the process to the level-1 subsystems subordinate to one level-2 subsystem is passed through what has been referred to by Crossman [17] as an aggregator or unifier prior to becoming an input to the level-2 subsystem. In turn, the feedback input to the level-2 subsystems is passed through another aggregator before it reaches the level-3 subsystem.

The idea of informational feedback aggregation, which will be elaborated upon later in this paper, is central to a hierarchical organizational model recently proposed by Crossman [17]. This model comes closer to being a true organizational cybernetic model than does Mesoravic's model in the sense that it explicitly incorporates general engineering (or engineering cybernetics) controllers. Each of these controllers models the control functions of human role incumbents at the different organizational levels. In terms of Mesarovic's model in Fig. 1, Crossman considers that each decision unit contains a controller the control output of which corresponds to the output of the relevant decision unit. The controlled system or effector corresponding to a particular controller is considered to be composed of this controller's or decision unit's subordinate decision units (i.e. "span-of-control" units) down the chain of command to and including the relevant level-0 process units. The above aggregator elements are also contained in such an effector. As mentioned above and as considered by Crossman, it is such (successively) aggregated effector output that is fed back to a higher-level decision unit or more directly to its controller element.

Another element of Crossman's model is the "multifier" which "interprets a single complex command or objective into a number of more elementary commands" ([17], p. 6). In terms of Mesarovic's model, Crossman then considers that each decision unit contains a multifier coupled serially to and 'upstream' of the controller element of the decision unit. Thus, a multifier serves to split a command input, which is also the corresponding decision unit's input, into separate objectives for each of the effectors controlled by this decision unit's controller element. If such multifier behavior is somewhat further generalized, as shown below in some detail, then multifiers may be considered as modelling managerial planning functions.

The organizational cybernetic model formulated by Crossman appears to be the first important effort to explicitly recognize the analogy between complex hierarchically integrated feedback control systems and organizations. Our description of this model has so far been aimed at providing only a very general outline of it. Some of its more detailed features may be inferred from our subsequent development of an alternative organizational cybernetic model that incorporates some of Crossman's model characteristics. In particular, the idea of control system "nesting" by means of the aggregator component is also central to this alternative model.

1.2 The Systems Relevance of Time-Span of Discretion

A significant parameter of organizational roles and one which has certain important normative implications for the hierarchical structure of an organizational cybernetic system is the so-called time-span of discretion concept developed by Elliott Jaques [24]. The model presented below was in fact initially and primarily motivated by what we felt was a need to undertake a systematic formulation of the time-span of discretion concepts by incorporating them into an organizational cybernetic model.

The time-span of discretion (TSD) idea, which provides a quantitative technique for measuring level of work (LOW) of both supervisory and non-supervisory roles, was first introduced in England by Jaques some decade and a half ago as an integral part of a general theory of work, differential compensation and individual progress and capacity. His work has been extensively reported in books and journal publications (eg., [24,25,26,27]).

In brief, the TSD method considers work as the exercise of discretion within prescribed limits of time and quality (and possibly resource deployment) and the LOW of a role as the longest time period that the role incumbent may exercise such discretion without necessarily being reviewed by his supervisor. These concepts are discussed below in detail. On the basis of a sample of several hundred roles, Jaques found a high correlation between the differentially distributed LOW estimates of these roles and the corresponding pay that the role incumbents felt fair for the work they were doing. Without making available the actual data, Jaques considers this high correlation as the empirical evidence of the feasibility of his TSD method for estimating LOW.

Jaques' general theory has been the subject of some praise and considerable criticism (eg., [2,6,21,22,38]). Much of the criticism has centered on his socio- and psycho-economic theory whereas his TSD method considered in isolation from its general context has fared quite well. Some reported studies (eg., [4,10]) have generally confirmed the feasibility of this method and have reported fairly high correlations between the LOW as measured by the TSD method and the corresponding job ratings obtained by traditional job evaluation methods. None of these reports presents any detailed analyses of the roles studied. Jaques himself presents only a very few and partly detailed accounts. Furthermore, no research hitherto reported (ref. [32] presents an account of the current status of TSD research as well as reported applications) seems to have made any effort to evaluate the basic underlying TSD ideas.

In view of this lack of any rigorous evaluation and systematic formulation of the TSD method and because of the unavailability of detailed TSD data, the research reported here had the following initial objectives:

(i) conceptualize the basic TSD ideas within a systems theoretic framework;

(ii) develop a mathematical formulation that offers mathematical precision in defining both TSD concepts and issues;

(iii) make an in-depth critical evaluation of the basic underlying TSD ideas on a theoretical basis and with reference to empirical data; and

(iv) make available some lacking detailed TSD data.

This dissertation essentially falls into two main parts. The first part is concerned with developing an organizational cybernetic model whereas the second part involves the formulation and analysis of the TSD concepts within the model framework. A separate appendix is devoted to presenting a detailed account of some of our own empirical TSD data.

The model to be developed, which emphesizes the planning and control functions performed by individual organizational role incumbents, will be somewhat more sophisticated than would strictly be required for a systematic TSD formulation. In particular, such typical organizational characteristics as sampled-data feedback and adaptation will be analyzed in some detail. Effector adaptation as well as the concept of fast-time internal effector model predictions will be incorporated into an initial proposal for a controller logic flow chart. As very little is known about such human cognitive characteristics in general, our presentation of the controller logic flow chart will admittedly be of a somewhat qualitative nature.

2. GENERAL MODEL FORMULATION OF ORGANIZATIONAL PLANNING AND FEEDBACK CONTROL SYSTEM (OPFCS)

2.1 System Elements and General Behavior

2.1.1 Preliminary Comments

We shall start off our primarily qualitative modelling effort with the simple premise that any industrial or other type of goal-oriented organization is a complex system or organism in which planning and feedback control are predominant characteristics. The basic mission of such a system is quite generally to increase the utility of some physical object(s) consistent with given goals (objectives, targets) by employing available resources - physical (equipment, plant buildings, non-human power), human (administrative skills, analytical skills, motor skills) and capital - so as to optimize system performance with respect to some performance criterion or criteria within certain constraints imposed by the system itself or by its environment. Within such a total system, the various planning functions are aimed at hierarchical factoring of global goals and performance requirements which the organizational control systems are in turn designed to accomplish in some optimal manner.

A total organizational planning and feedback control system (OPFCS) is composed of component OPFC systems which interact via their input-output interfaces giving the total system its characteristic structure. A complete description of the total system's behavior, which is determined by the way in which the inputs are transformed into its outputs, is conditional upon knowledge of its hierarchical structure and the behavior of its elements. The resolution level chosen depends, of course, to a great extent on the particular systems analysis or design objective. In our case, we are primarily interested in the superior-subordinate task relationships and the operation performed by individual role incumbents at different organizational levels. This relatively high-resolution approach is motivated by our objective of developing an OPFCS model into which the time-span of discretion concepts may be incorporated.

For the sake of generality, we shall consider some organization level-ℓ role incumbent $rI_{\ell i}$ whose direct responsibility is the composite operation or task

$$S_{\ell i} = S'_{\ell i} \, P_{\ell i} \tag{2.1}$$

where $P_{\ell i}$ and $S'_{\ell i}$ denote, respectively, some planning and closed-loop control operations as well as the associated systems.* Even though a

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*The operator or transform notation of eq.(2.1) simply denotes that the (composite) operation $S_{\ell i}$ is equivalent to the operations performed by the serially coupled or cascaded elements $P_{\ell i}$ and $S'_{\ell i}$; $P_{\ell i}$ being performed first. We shall consider these operators to be time-domain operators, i.e., the inputs to the corresponding systems are time-functions. If the systems are time-continuous, multivariate, linear and time invariant with impulse-response function matrices $H_{S_{\ell i}}$, $H_{P_{\ell i}}$ and $H_{S'_{\ell i}}$ and if the vector input and output of $S_{\ell i}$ is denoted, respectively, by $\overline{x}(t)$ and $\overline{y}(t)$, then we have the familiar convolution-integral relationship

$$\overline{y}(t) = S_{\ell i}[\overline{x}(t)] = \int_{-\infty}^{\infty} H_{S_{\ell i}}(\tau)\overline{x}(t-\tau)\,d\tau = H_{S_{\ell i}}(t)*\overline{x}(t)$$

Eq. (2.1) may then be equivalently expressed as

$$H_{S_{\ell i}}(t)* = H_{S'_{\ell i}}(t) * H_{P_{\ell i}}(t)*$$

If these systems are time-discrete, which would not seem to be untypical of organizational systems, convolution-summation operations replace the above convolution-integral operations. In the complex-frequency domain approach to systems analysis, the above convolutions are replaced by the matrix products

$$\overline{y}(s) = H_{S_{\ell i}}(s)\ \overline{X}(s) = H_{S'_{\ell i}}(s)\ H_{P_{\ell i}}(s)\ \overline{X}(s)$$

if the systems are time-continuous and

$$\overline{y}(z) = H_{S_{\ell i}}(z)\ \overline{X}(z) = H_{S'_{\ell i}}(z)\ H_{P_{\ell i}}(z)\ \overline{X}(z)$$

if the systems are time-discrete; the H..(s) and the H..(z) being the systems' transfer functions, the H..(z) are also referred to as pulse transfer functions. The same symbols have been used for some of these tight serial coupling primarily exists between the systems $P_{\ell i}$ and $S'_{\ell i}$ as indicated in eq.(2.1), information feedback generally occurs between these systems as commented upon later. Furthermore, interactions not accounted for in eq.(2.1) such as between $S'_{\ell i}$ and one or more $S'_{\ell i'}$ need to be incorporated into a complete system description. Similarly, the introduction of uncontrollable disturbance or noise inputs (external and internal) to $S'_{\ell i}$ and particularly to the effector (plant, controlled element) $E_{(\ell-1)i} \in S'_{\ell i}$* has to be accounted for. It is partly to compensate for such generally unpredictable disturbances that closed-loop as opposed to open-loop control is typical of any organizational system.

Initially, however, it will be assumed that eq. (2.1) essentially does apply as illustrated in Fig. 2 where the element $S'_{\ell i}$ is seen to resemble a conventional automatic control system (the disturbance input will be dropped later for schematic modelling simplicity). This simple model of some level-ℓ OPFCS, which will be further resolved and elaborated on step by step, will serve as the basic building block for our total modelling effort.

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functions because of notational simplicity although the functions are obviously not the same.

These dynamic relationships are only intended as quantitative elaborations on eq.(2.1) without necessarily implying that linearity and time invariance are justifiable assumptions. In fact and as will be mentioned briefly later in this thesis, quasi-linear modelling would appear to be more appropriate when dealing with real organizational systems so that "remnant" terms would need to be incorporated into the above equations.

*We shall be using set theoretic notions quite extensively throughout the dissertation and only in cases of possible ambiguity will the symbolism used be elaborated on. Thus, for example, $S_i \in S$ symbolizes that S_i is a subsystem or element of the system S. If S_i has been resolved, then $S_i \subset S$ will be used instead of $S_i \in S$ as when S_i is a "black box".

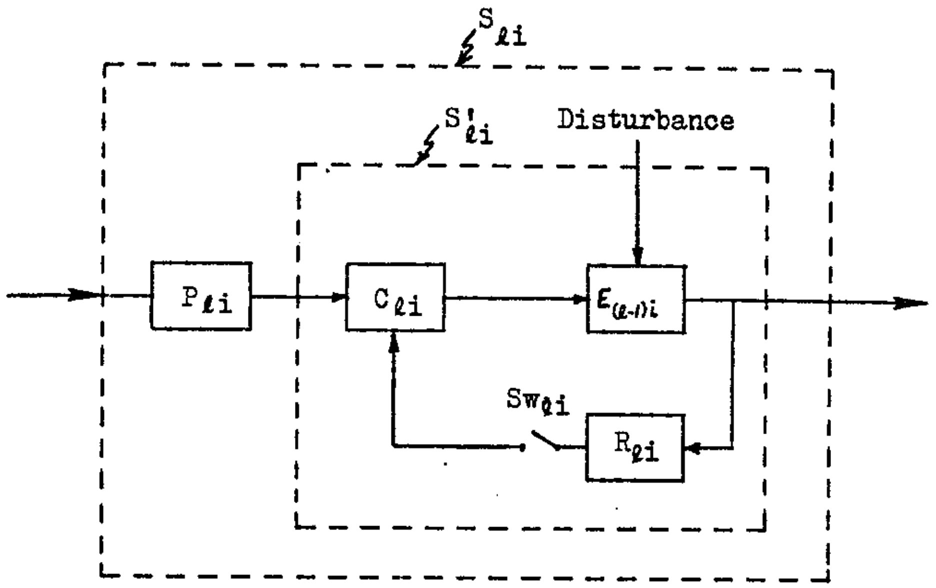

FIG. 2: SCHEMATIC MODEL OF A LEVEL-ℓ OPFCS

2.1.2 Planning

Planning will be used herein in the broad sense of deciding ahead of time what is to be done. In such general terms, the output of any planning system is a network of planned courses of action to be taken and the process is composed of such activities as (i) determining system structures*, goals and performance requirements needed to realize the goals, (ii) selecting and allocating resources and (iii) scheduling. By the term "goal" of a system is here meant the desired output state of the system at some future and generally fixed time point (terminal goal) or during some finite and fixed or theoretically infinite discrete or continuous time interval (non-terminal goal). The term "output state" as used here refers to the instantaneous value of the system's

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*This statement with respect to system structure determination will become more apparent as the low-resolution model of Fig. 2 is further resolved subsequently.

output vector assuming, of course, that the corresponding system attributes are quantifiable. Unless otherwise specified, goals will be considered as terminal goals, dynamic system performance requirements or standards being non-terminal goals. Thus, typical goals of an industrial production system are to attain an accumulated value of production of \$x for some product type by the end of the year, a total of \$y in resource deployment (cost) at the scheduled completion point of some development project (y is presumably some realistic minimum), etc.

The planning within an organization is generally aimed at realizing the organization's global goals. These goals are highly general and it is the objective of the hierarchical planning system to translate these into more precise and operational subgoals that are ultimately associated with the variables of the lowest-level systems such as those performing the process of transforming raw material into products, faulty items into serviced ones, etc. Similarly and partly as a result of goals becoming more specific, the desired means of achieving these goals become more accurately prescribed with decreasing planning levels.

Planning is to some extent a function of every role incumbent in an organization. The level-ℓ role incumbent $rI_{\ell i}$ has to perform the planning process $P_{\ell i}$ for his organizational subsystem $S_{\ell i}$ within constraints or prescriptions imposed upon him (i) from above through higher level plans primarily and most directly those from the immediate superior(s)' planning system $P_{(\ell+1)}$, (ii) from "across" and "diagonally" due to interactions between $P_{\ell i}$ and one or more $P_{\ell i'}$ and $P_{\ell' i'}$, (iii) from within through his subsystem's resource limitations and (iv) perhaps even directly from the total system S_L environment. In turn, the output plans of $P_{\ell i}$ guide and constrain lower-level planning processes.

2.1.3 Feedback Control

The control functions within an organization are designed to ensure that goals, planned performance requirements and schedules are being met. On the basis of information feedback, actual performance is being compared with standard performance and discrepancies between the two actuate control elements or initiate control actions tending to null out such errors. The level-ℓ role incumbent $rI_{\ell i}$ is directly responsible for the control system $S'_{\ell i}$ (see Fig. 2 above) consisting of the following elements:

1) The Controller $C_{\ell i}$, of which $rI_{\ell i}$ is the human component, operates on the planned or desired $S'_{\ell i}$ performance ($P_{\ell i}$ output) and feedback information about actual $S'_{\ell i}$ performance to maintain correspondence between them by taking corrective actions whenever significant discrepancies occur. Such actions are the control inputs to the effector $E_{(\ell-1)i}$.

2) The Effector $E_{(\ell-1)i}$ is the system whose output is being controlled by $C_{\ell i}$. For $\ell > 1$, the human components of $E_{(\ell-1)i}$ are the incumbents of $rI_{\ell i}$'s total (informal) "span-of-control role set" $\{rI_{(\ell-1)ij}\ ;\ j \in I_{\ell i}\}$ and these role incumbents' subordinates down the chain of command; the index set $I_{\ell i} = \{1, \ldots, I_{\ell i}\}$. Furthermore and as commented upon later, $rI_{\ell i}$ may himself be an element of $E_{(\ell-1)i}$. Physical resources such as equipment, tools, plant buildings, etc. are also contained in $E_{(\ell-1)i}$. For $\ell=1$, E_{0i} may be composed of some machine(s) or physical process directly converting raw material into product. The control actions applied to E_{0i} by rI_{1i} or more precisely by C_{1i} may entail the "proper" force or movement applied to a con-

trol device (lever, knob or wheel), handtool, etc.

3) The Receptor $R_{\ell i}$ or feedback element is the system whereby $C_{\ell i}$ receives feedback information about the true state of the output of $E_{(\ell-1)i}$. The process involves sensing or measuring by means of measuring sensors, transducing or converting (frequently coding/decoding) for transforming information from one form to another, communication channels as media for information transmission, and data recording and display.

4) The Sampler $Sw_{\ell i}$ or sampling switch takes explicitly into account the typical discontinuous nature of the feedback information and thus models the sampling or review behavior of $rI_{\ell i}$. The $Sw_{\ell i}$ operation will be analyzed in some detail in a later section.

2.1.4 Aggregation

Data aggregation or compression is a typical data processing operation in any organization aimed at reducing the redundancy and volume of data or messages communicated throughout the organization while avoiding too much loss in their information content. Filtering out insignificant data may also accompany such aggregation. In order to illustrate one such particular type of data aggregation contained in the $E_{(\ell-1)i}$ operation, $E_{(\ell-1)i}$ will be analyzed at one lower resolution level.

The subordinate role incumbents $rI_{(\ell-1)ij}$ of $rI_{\ell i}$, which are components of the system $E_{(\ell-1)i}$, are directly responsible for the operations

$$S_{(\ell-1)ij} = S'_{(\ell-1)ij}\, P_{(\ell-1)ij} \;;\; j=1,\ldots,I_{\ell i}$$

where, as analogous to eq.(2.1), S'... denotes closed-loop control operations and P... planning operations. The associated systems are elements of the effector $E_{(\ell-1)i}$ and their inputs are the command or control instructions from $C_{\ell i}$. Similarly, for a given i and j, the controller $C_{(\ell-1)ij} \subset S'_{(\ell-1)ij}$ is directly and serially coupled to the systems

$$S_{(\ell-2)ijk} = S'_{(\ell-2)ijk}\, P_{(\ell-2)ijk}\ ;\ k=1,\ldots,I_{(\ell-1)ij}$$

The output variables of the system $E_{(\ell-2)ijk}$ being controlled by $C_{(\ell-1)ij}$ may refer to the same type of system attributes as those of $E_{(\ell-1)i}$ being controlled by $C_{\ell i}$. The former variables are directly associated with each of the systems $S'_{(\ell-2)ijk} \subset E_{(\ell-2)ijk}$ whereas the corresponding output variables of $E_{(\ell-1)i}$ are generally some aggregate of the $E_{(\ell-2)ijk}$ output variables. Thus, in general terms, whenever $rI_{\ell i}$ is assigned some tasks whose subtasks are allocated to the $rI_{(\ell-1)ij}$ and then are broken down further and allocated to the $rI_{(\ell-2)ijk}$, $rI_{\ell i}$ is mainly concerned with the overall result of the task performance of the $rI_{(\ell-2)ijk}$ rather than the more detailed aspects of the individual $rI_{(\ell-2)ijk}$ task performaces with which $rI_{(\ell-1)ij}$ concerns himself. In terms of the "aggregator" $A_{(\ell-1)ij}$ (after Crossman [17]), we may consider that the output of $S_{(\ell-1)ij}$ is passed through $A_{(\ell-1)ij}$ prior to becoming an output of $E_{(\ell-1)i}$ and fed back to the controller $C_{\ell i}$. Thus,

$$E_{(\ell-1)ij} = A_{(\ell-1)ij}\, S_{(\ell-1)ij}$$

where $E_{(\ell-1)ij} \subset E_{(\ell-1)i}$ and for $j=1,\ldots,I_{\ell i}$, the structure of the system $S_{\ell i}$ at the present resolution level is that illustrated in Fig. 3 below. In this schematic model, the element $E_{(\ell-1)i0}$ accounts for any level-(ℓ-1) effector operation(s) performed by $rI_{\ell i}$. This operation, which for simplicity will not be explicitly carried along in our subse-

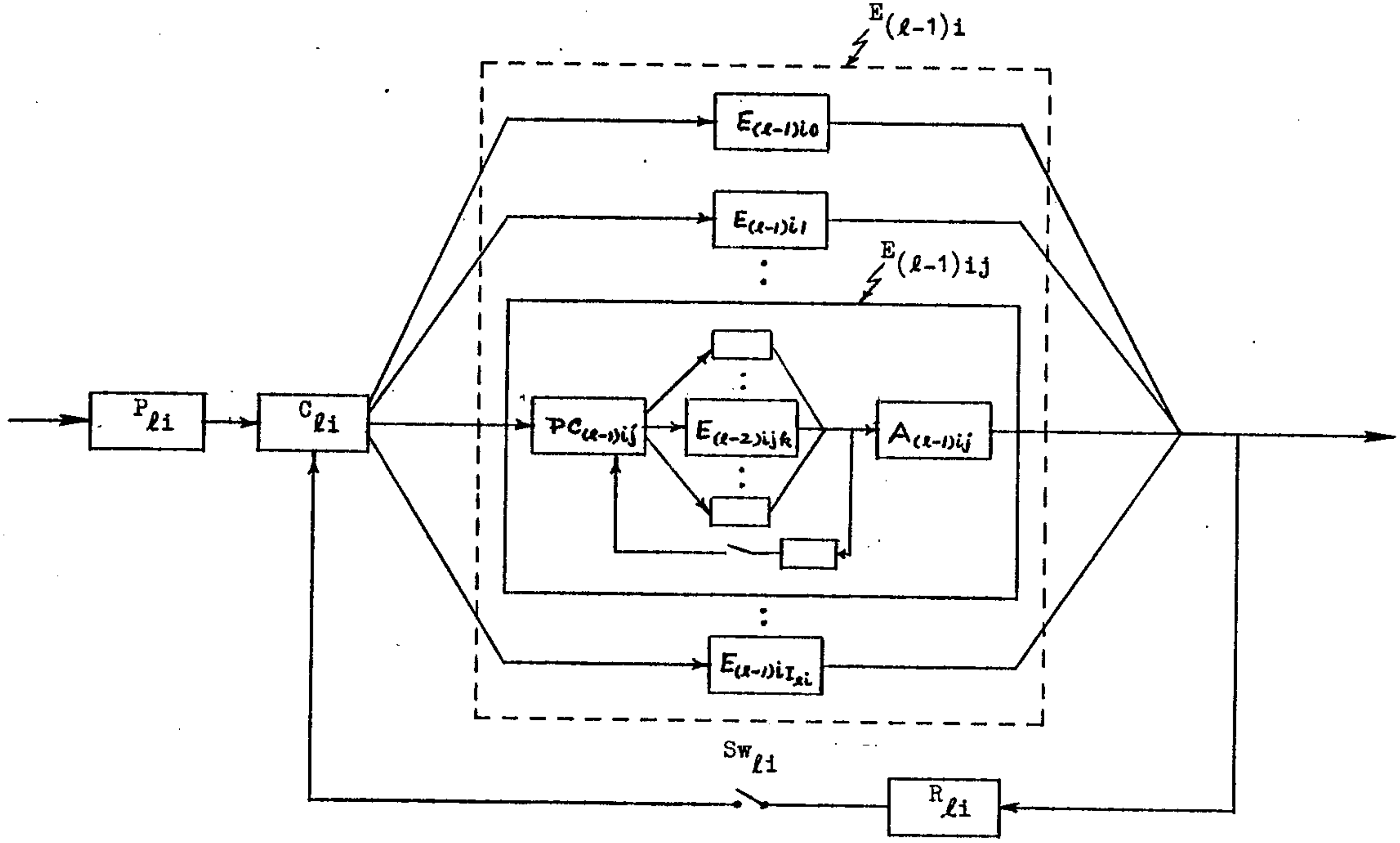
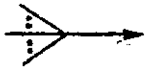


FIG. 3: A LEVEL-ℓ OPFCS EMPHASIZING PARTIAL HIERARCHICAL STRUCTURE

Comment: The representation  in this figure simply means that the (column) vectors $\overline{x}_1,\ldots,\overline{x}_i,\ldots,\overline{x}_n$, say, are combined into a new vector $\overline{x} = \left[\overline{x}_1^{\tau}\ldots\overline{x}_i^{\tau}\ldots\overline{x}_n^{\tau}\right]^{\tau}$; τ denotes the transpose.

quent model formulation, includes activities performed by $rI_{\ell i}$ that do not appropriately fall within his planning and control functions.*

Consider now, for a given i and j, that $\bar{y}_{ijk}(t)$ is the n_{ijk}-vector output of $E_{(\ell-1)ijk}$ where $n_{ijk}=n_{ij}$ for $k=1,\ldots,I_{(\ell-1)ij}$. Furthermore, consider that the elements of these $I_{(\ell-1)ij}$ vectors are so ordered that their i-th element refers to the same type of system attribute (eg., resource deployment, quality, etc., see subsequent sec. 2.2). Then a mathematical model of $A_{(\ell-1)ij}$ would not untypically appear to be the following

$$\bar{y}_{ij}(t) = A_{(\ell-1)ij}\left[x_{ij}(t)\right] = \sum_{k=1}^{I_{(\ell-1)ij}} y_{ijk}(t)$$

where $\bar{x}_{ij}(t) = (\bar{y}^{\tau}_{ij1}(t)\ldots\ldots\bar{y}^{\tau}_{ijI_{(\ell-1)ij}}(t))^{\tau}$; the superscript τ denotes the transpose of the corresponding column vectors. Similarly for the output vector $\bar{y}_i$ of $A_{\ell i}$ (= output of $E_{\ell i}$ where $E_{\ell i} = A_{\ell i}\, S_{\ell i}$)

$$\bar{y}_i(t) = A_{\ell i}\left[(\bar{y}^{\tau}_{i1}\ldots\bar{y}^{\tau}_{ij}\ldots\bar{y}^{\tau}_{iI_{\ell i}})^{\tau}\right] = \sum_{j=1}^{I_{\ell i}} \bar{y}_{ij}(t).$$

A more realistic and general form of the operator $A_{\ell i}$ would be to have a partial summation of some of its input components whereas others simply pass through $A_{\ell i}$ (i.e., $A_{\ell i}$ is a partial unitary operator) and/or still other component inputs are filtered out. Such partial filtering

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*In particular, the $E_{(\ell-1)i0}$ operation incorporates tasks which $rI_{\ell i}$ carries out (i) concurrently with similar tasks performed by some of the $rI_{(\ell-1)ij}$ or (ii) instead of some of these subordinate role incumbents who may also at times perform these type of tasks. Thus, for example, a chief engineer may design some components of an assembly whereas the remaining components are designed by some of his subordinate draftsmen. The chief engineer ($rI_{\ell i}$) may decide to assume such design responsibility because he feels he is best qualified for it and/or because the workload of his subordinates does not permit him to delegate this design task.

would occur whenever $C_{\ell i}$, as a result of some $P_{\ell i}$ decision, controls some $E_{(\ell-1)i}$ output(s) which is of no explicit concern to $C_{\ell+1}$. To identify $A_{\ell i}$ as an aggregator is thus not altogether satisfactory but the term was chosen because data aggregation appears to be a predominant characteristic of $A_{\ell i}$.

2.2 System Variables

Up to this point, general reference has been made to system inputs and outputs without suggesting what types of attributes they are associated with. It has been assumed that the various systems may be multivariate so that their inputs and outputs are vector quantities, each element of which is the value of one system attribute or property at some arbitrary time t. Some attributes of organizational systems may, of course, not be quantifiable in which case some alternative but closely related and measurable attributes may be and typically are considered. Thus, for example, absenteeism is frequently considered a substitute for employee morale and faculty teaching quality is considered in terms of number of publications.

For an analysis of the detailed structure and dynamics of the above OPFCS, the choice of variables to be considered has to be elicited from the role incumbent $rI_{\ell i}$ for system $S_{\ell i}$, $rI_{(\ell-1)ij}$ for $S_{(\ell-1)ij}$, etc. This choice also depends to some extent upon the particular interest of the systems' analyst as long as significant causal input-output relationships for the individual systems are accounted for. Such typical time-varying quantities are suggested to be the following:

1) Resource deployment (cost or its antithesis, profit)

2) Progressive degree of completion - This applies to terminal-type

projects and is measured on a scale from 0 to 1. In terms of the man-hours (man-days, man-months, etc.) m(t) accumulated on some project at time t and the total man-hours M required for the project completion, progressive degree of project completion at time t is considered equal to m(t)/M. If a project entails the production of P components and the accumulated production volume at time t is denoted by p(t), then p(t)/M is our measure of the progressive degree of completion.

3) Quantity - This attribute when associated with non-terminal (on-going) operations is considered equivalent to the progressive degree of completion for terminal operations. Quantity may refer to production volume, sales volume, inventory level, etc.

4) Quality - This is a property of the physical output of a system such as dimension tolerances and surface finish of manufactured components, composition of chemical substances, neatness of a written report, aesthetics of a remodelled office, etc. This type of attribute is frequently set implicitly based on a mutual understanding between $rI_{\ell i}$ and the $rI_{(\ell-1)ij}$ and is more often than not non-quantifiable. This interpretation of quality has to be distinguished from that of the performance quality of, say, the control system $S'_{\ell i}$. The performance quality of $S'_{\ell i}$ is measured relative to some performance criterion (or criteria) involving some form of minimization of errors between desired and actual $S'_{\ell i}$ output, the above quality variable being one component of the $S'_{\ell i}$ input and output vectors.

5) Safety (or its antithesis, injury rate).

2.3 System Structure

2.3.1 Some General Comments

The structural analysis of the general level-ℓ OPFCS $S_{\ell i}$ has so far been made at a rather low resolution level. For some $\ell \geq 2$, the system $S_{\ell i}$ has been considered at what maybe referred to as the hierarchical resolution levels 1 (see Fig. 2) and 2 (see Fig. 3). In the former case, the structure of $S_{\ell i} = \{P_{\ell i}, C_{\ell i}, E_{(\ell-1)i}, R_{\ell i}, Sw_{\ell i}\}$ was considered without decomposing the effector $E_{(\ell-1)i}$ whereas in the latter case, $E_{(\ell-1)i}$ was decomposed into the set of effector elements $\{E_{(\ell-1)ij} \,;\, j \in I_{\ell i}\}$ each $E_{(\ell-1)ij}$ of which is itself a level-$(\ell-1)$ OPFCS plus the serially coupled aggregator $A_{(\ell-1)ij}$. The ultimate hierarchical resolution of the total OPFCS will be considered in the next section.

The $S_{\ell i}$ elements $P_{\ell i}$, $C_{\ell i}$, $R_{\ell i}$, and $Sw_{\ell i}$ have not yet been resolved. In particular, a realistic assumption may perhaps be to consider that the last three system elements are resolvable into the set of components $\{C_{\ell ij}, R_{\ell ij}, Sw_{\ell ij} \,;\, j \in I_{\ell i}\}$ where $C_{\ell ij}$, $R_{\ell ij}$ and $Sw_{\ell ij}$ are directly associated with the effector $E_{(\ell-1)ij}$. This decomposition results in the organizational closed-loop control systems $S'_{\ell ij} = \{C_{\ell ij}, E_{(\ell-1)ij}, R_{\ell ij}, Sw_{\ell ij}\}$ $(j=1,\ldots,I_{\ell i})$. In general, the $S'_{\ell ij}$ will not be independent since interactions or cross couplings may exist between them. Another reason why this decomposition assumption will not be made in this paper is that nothing would be gained in terms of simplifying our model by so doing. A subsequent section will be concerned with what is believed to be a more plausible type of decomposition.

2.3.2 Structure of S_L

Consider the total level-$(\ell=L)$ OPFCS $S_L = \{P_L, C_L, E_{(L-1)}, R_L, Sw_L\}$

whose composite operation may be the direct responsibility of a company president rI_L. Since the preceding general analysis applies to any level-ℓ OPFCS, these ideas may be employed in formalizing the structure of S_L through the following stepwise resolution procedure:

1) Hierarchical resolution level 1 - The structure of S_L is that represented in Fig. 2 above with ℓ=L and the subscript i dropped.

2) Hierarchical resolution level 2 - The structure of S_L is that illustrated in Fig. 3 above with the notational change that the subscripts ℓi, $(\ell-1)i$, $(\ell-1)ij$ and $(\ell-2)ijk$, respectively, are replaced with L, (L-1), (L-1)i and (L-2)ij. It is at this resolution level that the aggregators $A_{(L-1)i}(i=1,\ldots,I_L)$ initially and explicitly enter into our OPFCS model.

3) Hierarchical resolution level $2<h\leq L$ - Each effector $E_{(L-2)ij}$ is next decomposed into a level-(L-2) OPFCS $S_{(L-2)ij}$ together with a serially coupled aggregator $A_{(L-2)ij}$ where $S_{(L-2)ij} \ni E_{(L-3)ij} = \left\{E_{(L-3)ijk} ; k\in I_{(L-2)ij}\right\}$. At the next lower hierarchical resolution level h=4, the $E_{(L-3)ijk}$ are further resolved, etc. By following this resolution procedure down the (informal) classical organization chart of a firm until h=L, we end up with a schematic model of the S_L structure as illustrated in Fig. 4 below for L=4. In particular, this model corresponds to the two divisions of the naval facility analyzed below in connection with our time-span of discretion studies.

The proposed structure of some general S_L and also $S_{\ell i}$ for $\ell<L$ is admittedly somewhat simplified up to this point. It will be the subject of a subsequent section #2.3.4 to make certain further generalizations.

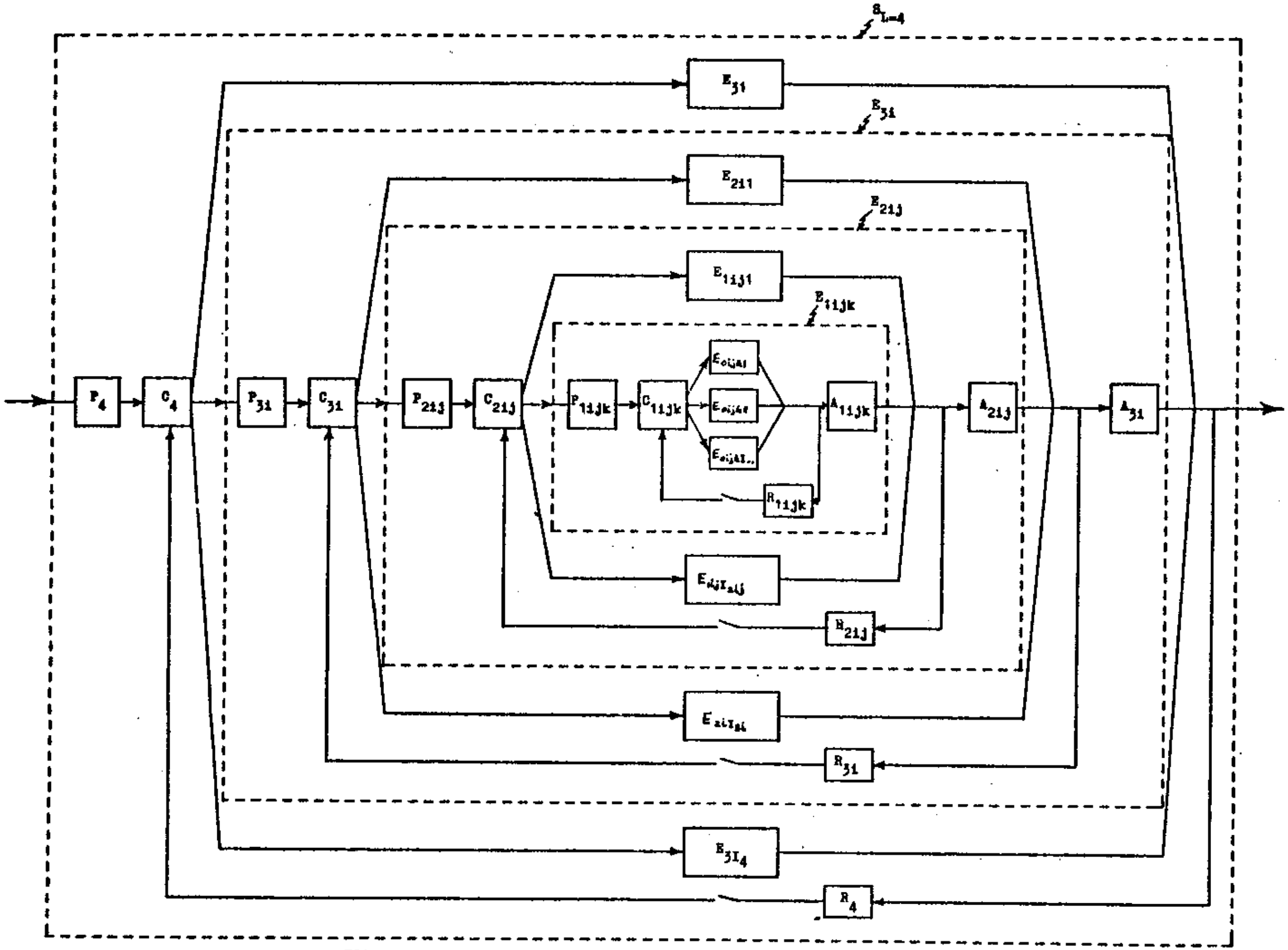

FIG. 5: SCHEMATIC MODEL OF THE STRUCTURE OF A TOTAL LEVEL - 4 OFFCS

2.3.3 The Decomposition $S_{\ell i} = \left\{S^{km}_{\ell i}\right\}$

Up to this point in our organizational systems analysis, we have considered the total or composite operation $S_{\ell i}$ performed by an OPFCS $S_{\ell i}$ or, less precisely, by the role incumbent $rI_{\ell i}$ who is the individual directly responsible for the $S_{\ell i}$ operation. Various phases of the $S_{\ell i}$ operation are allocated by $rI_{\ell i}$ to his immediate subordinates $\left\{rI_{(\ell-1)ij} ; j \in I_{\ell i}\right\}$ or, more precisely, to his subordinate OPFCS $\left\{S_{(\ell-1)ij} ; j \in I_{\ell i}\right\}$ for which the $rI_{(\ell-1)ij}$ are in turn directly responsible. During some time interval

$$T_{\ell i} = \left\{t : t_{0\ell i} \leq t \leq t_{1\ell i}\right\}$$

$rI_{\ell i}$ generally performs a number of distinct but not necessarily independent type of tasks $S^{k}_{\ell i}(k=1,\ldots,K_{\ell i})$. The particular task $S^{k}_{\ell i}$ is performed $M^{k}_{\ell i}$ times during $T_{\ell i}$. In the most general case, the $S^{k}_{\ell i}$ task is "different" when performed the m-th time than when it is performed the m'-th time during $T_{\ell i}$. It will thus be considered that $S^{k}_{\ell i} = \left\{S^{km}_{i} ; m \in M^{k}_{i}\right\}$ where $S^{km}_{\ell i}$ denotes both a task or operation and the corresponding system. In terms of the systems $S^{km}_{\ell i}(m=1,\ldots,M^{k}_{\ell i})$, the above term "different" is meant to imply that the dynamics as well as the structure of these $S^{km}_{\ell i}$ may be different.

Thus, if $K_{\ell i}$ and $M^{k}_{\ell i}$ denote the index sets

$$K_{\ell i} = \left\{1,\ldots,K_{\ell i}\right\} \quad \text{and} \quad M^{k}_{\ell i} = \left\{1,\ldots,M^{k}_{\ell i}\right\}$$

then we are considering the decomposition

$$S_{\ell i} = \left\{S^{k}_{\ell i} ; k \in K_{i}\right\} = \left\{S^{km}_{\ell i} ; k \in K_{\ell i}, m \in M^{k}_{\ell i}\right\}$$

Each member of the task set $S_{\ell i}$ has to satisfy some condition or possess a certain property, the precision of which determines the uniqueness of the above decomposition. The uniqueness question will be taken up later in connection with our evaluation of the time-span of discretion concepts for which the $S_{\ell i}^{km}$ tasks are the basic entities. For the time being, it is simply assumed that there is some "natural" way of decomposing $S_{\ell i}$ into elementary tasks $S_{\ell i}^{km}$ the resolution level of which partly depends on the analyst's interests. If, for example, $rI_{\ell i}$ is a chief engineer in some small manufacturing plant, these tasks may be the following: performs minor design projects, prepares bids, supervises production and component testing, trains a subordinate draftsman, oversees and reports on the shops' safety programs, etc.

2.3.4 Some Further Notes on Systems Interactions

In our general model formulation of some OPFCS, no element of the total OPFCS S_L has been assumed to be completely independent of any other S_L elements. However, even the complex network of interactions or coupling patterns schematically modelled in Fig. 4 above must be considered as too simplistic for a general level-L organization. This somewhat over-simplified structure is caused by the omission of cross couplings between the various effectors and their elements. Such couplings have so far not been explicitly incorporated into our model formulation in order to maintain a model structure of comprehensible complexity and because the coupling patterns explicitly considered would generally appear to be the most significant or strongest ones.

We have essentially taken the classical Weberian bureaucratic model approach when considering the structure of the total OPFCS S_L and its component OPFCS. Emphasis has been placed on the pyramidal structure and hierarchical coordination of organizational activities or hierarchical coupling patterns. In spite of all the criticism of this structural approach, (eg., [53]) the great majority of organizations still seem to operate on this principle. Furthermore, and to account for the modern and more flexible view of organization structure, we may consider the present state of our structural model as a general point of departure. It is beyond our present objectives, however, to generalize our model to incorporate the total spectrum of views on organization structure whether descriptive of existing organizations or purely normative. Only a few extensions will be briefly considered.

Firstly, the point of effector couplings needs some mentioning. It should be apparent from the preceding analysis that the possibility of parallel and/or feedback couplings existing between any of the effectors has not been excluded from the model. These couplings, which are primarily facilitated by not assuming that the controllers $C_{\ell i}$ are necessarily decomposable into completely independent component controllers each associated with an effector $E_{(\ell-1)ij}$, are "indirect" couplings*. In general and for some given organization, however, the effectors may also be directly cross coupled. The nature of such couplings will only be considered through the following admittedly incomplete set of propositions:

Proposition 1: The cross couplings between level-ℓ effectors are most significant or strongest for those associated with tasks originating from the same single task of a higher-than-ℓ level effector and particularly a level-$(\ell+1)$ effector.

Proposition 2: For effectors associated with individual role incumbents' tasks, cross couplings are typically significant when the same individual is directly responsible for these tasks and when the tasks are performed during overlapping time intervals.

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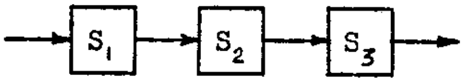
*The term indirect coupling between two systems signifies that the interaction between the two occurs via one or more intervening systems, eg.:



where an indirect serial coupling exists between S_1 & S_3 whereas S_1 & S_2 and S_2 & S_3 are directly and serially coupled.

<u>Proposition 3</u>: The cross couplings primarily occur between same-level planning elements although direct cross or rather diagonal couplings may exist between different-level planners.

In order to illustrate these effector interactions, consider the system $S^{km}_{\ell i}$, which is only one of the OPFC systems belonging to the level-$(\ell+1)$ OPFCS $S^{k'm'}_{\ell+1}$. In terms of the human role incumbent components of these systems, we are simply considering that $rI_{\ell+1}$, who is directly responsible for the task $S^{k'm'}_{\ell+1}$, allocates the set of component tasks $\left\{S^{\bullet\bullet}_{\ell i}\ ;\ i\in I^{k'm'}_{\ell+1}\right\}$ to his immediate subordinates $\left\{rI_{\ell i} ; i\in I^{k'm'}_{\ell+1}\right\}$; $I^{k'm'}_{\ell+1} \subset I_{\ell+1}$ where $I_{\ell+1}$ denotes the span-of-control role set of $rI_{\ell+1}$. These level-ℓ role incumbents may in turn delegate some of their work to their subordinates, etc. In particular, $rI_{\ell i}$ may allocate some elements of his task $S^{km}_{\ell i}$ to his subordinate role incumbents $\left\{rI_{(\ell-1)ij}, j\in I^{km}_{\ell i}\subset I_{\ell i}\right\}$. Let $S^{km}_{(\ell-1)ij}$ denote such an operation allocated to $rI_{(\ell-1)ij}$ and assume that, for the sake of generality, $S^{km}_{(\ell-1)ij}$ consists of the distinct set of tasks $\left\{E^{km}_{(\ell-1)ijo}\ ;\ o\in O^{km}_{(\ell-1)ij}\right\}$.

In the light of this notational background, the above cross-coupling propositions may be incorporated into our model of a general level-ℓ OPFCS structure as illustrated in Fig. 5 below.

In addition to cross couplings (or, if we like, diagonal couplings) between $P_{\ell i}$ and one or more $P_{\ell' i'}$ where possible, as mentioned under propositon 3, $\ell' > \ell$, $P_{\ell i}$ may also be directly (and partially or weakly) coupled to $C_{\ell' i'}$. Such coupling is characteristic of the so-called matrix organizations for which typically a role incumbent $rI_{\ell i}$ may have more than one immediate superior.

An open-system point which needs to be incorporated into our model is the general fact that some component OPFCS $S_{\ell i} \subset S_L$ may directly in-

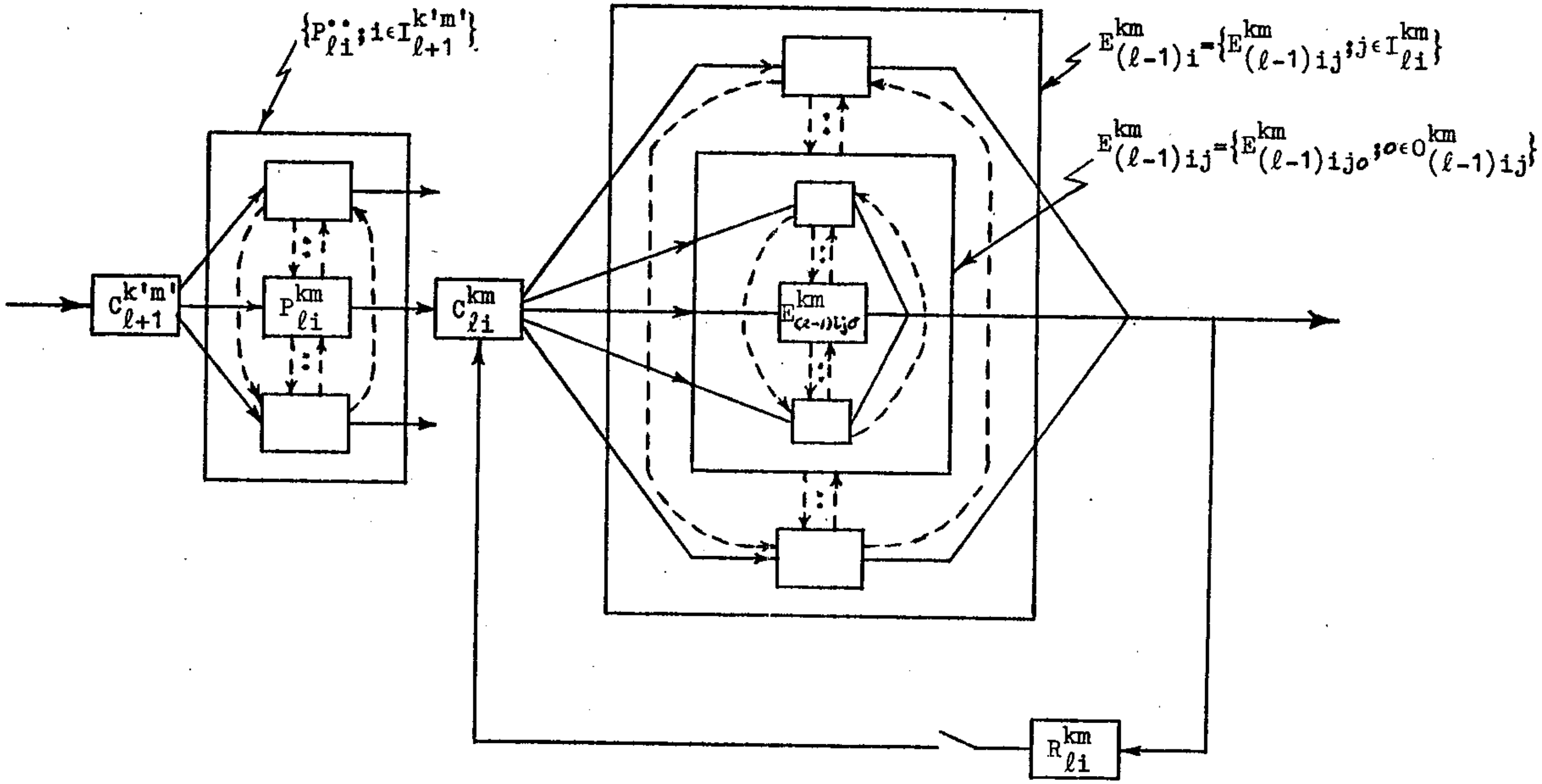


FIG. 5: SCHEMATIC MODEL OF CROSS-COUPLING STRUCTURE (Dashed lines indicate cross couplings)

(The indicated cross couplings between $E^{km}_{(\ell-1)ij}$ and the "two" other $E^{km}_{(\ell-1)i}$ elements are to be interpreted as directly involving the elements $E^{km}_{(\ell-1)ij\sigma} \in E^{km}_{(\ell-1)ij}$).

teract with the environment E_L of the total system S_L. The interactions between E_L and $S_{\ell i}$ have so far been considered to be indirect in the sense that they occur via higher-than-ℓ OPFC systems including S_L. The inclusion into our model of a direct interface between some $S_{\ell i}$ and E_L would be accomplished through a direct serial and also perhaps feedback coupling between $S_{\ell i}$ (or $E_{\ell i}$) and E_L. Such interactions would typically occur between an organizational sales unit and a customer and are also well exemplified in the following case study:

The engineering department of a firm producing diesel-driven electric generator sets is mainly concerned with the engineering design of generator bases, housings, instrument panels, fuel tanks and various pieces of auxiliary equipment. Although some minor manufacturing is done by the firm, the bases, panels and fuel tanks are manufactured by sub-contractors. The firm's two draftsmen and designers perform most of the designs and drafting generally loosely supervized by their immediate superior, the chief engineer. It is quite typical for one draftsman-designer to communicate directly with a sub-contractor regarding interpretation and modifications of designs. After studying the design of a base and perhaps starting to work on it, the sub-contractor occasionally contacts the draftsman-designer to suggest some modifications to make the base easier to manufacture or simply to improve its design, eg., weld generator mounting plates on side channels instead of mounting generator directly on the channels. The draftsman-designer then cooperates with the sub-contractor in producing a modified base design. Such design changes may occur with the chief engineer having only a superficial knowledge about it. Only if a design change is quite extensive involving modifications of other generator components such as the housing unit and/or if the change results in substantial increase in manufacturing cost, will the chief engineer necessarily be directly involved.

2.4 Further Control System Characteristics

2.4.1 The Feedback Monitoring Process

Typical of any complex time-shared human control task is the feedback intermittency as accounted for in our model by the sampler $Sw_{\ell i}$. This discontinuous nature of the human operator has been the subject of some research (i) in single-axis manual tracking (i.e., for $\ell=1$ with one linear effector E_{0i} with simple dynamics) (eg., [9,48]). (ii) into the visual sampling behavior of human process operators (eg., [14,15,40]) and (iii) on supervisory sampling in the more general case of $\ell \geqslant 2$ [41]. For the purpose of this paper, only a very general analysis of the $Sw_{\ell i}$ behavior is attempted for any ℓ. The primary motivation for such preliminary analysis is the apparent close relationship between this sampling process and the time-span of discretion concepts to be introduced below.

Consider in particular the system $E^{km}_{(\ell-1)ij} \subset E_{(\ell-1)i}$ whose (single) task is the direct responsibility of some $rI_{(\ell-1)ij}$. Let $\overline{y}_{ij}(t)$ denote the output vector of $E^{km}_{(\ell-1)ij}$, which is only a component vector of the total $E_{(\ell-1)i}$ output. Furthermore, let $Sw^{km}_{\ell ij}$ be the element of $Sw_{\ell i}$ operating directly on $\overline{y}_{ij}(t)$ and assume that the relevant receptor ($R_{\ell i}$) component operator is unitary (i.e., the corresponding transfer-function matrix is an identity matrix if linearity applies). Then, mathematically, we have that

$$\overline{y}^{*}_{ij}(t) = Sw^{km}_{\ell ij}\left[\overline{y}_{ij}(t)\right] = U^{km}_{\ell ij}(t)\overline{y}_{ij}(t)$$

where $U^{km}_{\ell ij} = \left\|u^{km}_{\ell ijp}\right\|$ is a diagonal matrix-valued time-function, $u^{km}_{\ell ijp}$ being a scalar-valued sampling function (or carrier function in the terminology of modulation in communication theory). If $t^{km}_{\ell ijpn}$ denotes the n-th sampling instant, then it is proposed that

$$u^{km}_{\ell ijp}(t) = \begin{cases} 1 \text{ for } t=t^{km}_{\ell ijpn} \text{ ; } n=1,2,\ldots \\ 0 \text{ otherwise.} \end{cases}$$

Even though this type of sampling functions would appear to be the most typical one, a sequence of finite-width pulses or a mixture of zero width (as above) and finite-width pulses may also apply especially perhaps for lower-level systems such as for $\ell=1,2$. Thus, for example, an operator rI_{1i} controlling the operating condition of some continuous physical process may, for some period following start-up and initial setting of regulator or valve, continuously check the value of the output variable (actual operating condition). If the actual (steady-state) output does not get in line with the desired output, then the operator adjusts the regulator and again monitors the output continuously until the new equilibrium is reached. If there is still a discrepancy between actual and desired output, the above procedure is repeated until this discrepancy is eliminated. Once the proper operating condition is reached, the operator intermittently makes quick checks of the output to ensure that disturbances, both external and internal to the process, do not cause it to get out of the proper balance again. If this does occur, then the above procedure is repeated.

For given i,...,m,p, the sampling instants $t^{km}_{\ell ijpn}$ and hence the sampling interval lengths $T^{km}_{\ell ijpn} = t^{km}_{\ell ijpn} - t^{km}_{\ell ijp(n-1)}$ may be fixed (constant or vary deterministically) or random; if finite sampling durations apply, then these would generally appear to be random. Because of some periodic reporting procedures employed by most organizations, constant sampling interval lengths are quite common, especially perhaps for $\ell \geq 2$. Thus, $T^{km}_{\ell ijpn} = 1$ month for all n is common when p is associated with resource deployment or cost. During our own field studies, sampling interval lengths have been found to range from a few seconds for $\ell=1$ to several weeks for $\ell\geq2$.

It is not uncommon that $rI_{\ell i}$ does not review some properties associated with a project allocated to $rI_{(\ell-1)ij}$ until the project has been completed or even until some time thereafter. That is, the control system $S'_{\ell i}$ may be partially open loop. On the basis of our own field data such open-loop control may particularly apply to the quality variable for terminal projects as exemplified in the following case study: An engineer (rI_{2ij}) of a semi-manufacturing firm was assigned by rI_{3i} (chief engineer) a scheduled 1-week design task. Some of the physical properties of the required components, such as their various dimensions, were specified as real dimensions, eg., 5"±0.001", while others were left unstated but implicitly understood to exist and the remaining ones had to be calculated and extracted from similar previous designs. Throughout the 1-week period, rI_{3i} made only casual checks of this design effort and then mainly to evaluate the progress rather than to make in-depth checks of the various dimensions. Instead, rI_{3i} would rely on an indirect review taking place when these components had been manufactured (according to the design) and were being assembled. Had any tolerance limits been exceeded or any dimensions incorrectly arrived at by rI_{2ij}, then rI_{3i} would have been notified about it during assembly, which was completed about 1 month after the design was finished.

In general, the sampling strategy adopted by $rI_{\ell i}$ (or $Sw_{\ell i}$) is aimed at maintaining optimal operation of the control system $S'_{\ell i}$.

Partly based on our own empirical observations, the choice of the sampling-function matrix $U_{\ell ij}^{km}$ is partially determined by the following factors:

1) The extent to which disturbances or noise are being introduced into $S'_{\ell i}$ and particularly into the effector $E_{(\ell-1)ij}^{km}$; increasing noise power tends to increase the mean sampling frequency.

2) The predictability of the $E_{(\ell-1)ij}^{km}$ output, which is clearly related to #1.

3) The degree of complexity of $E_{(\ell-1)i} \supset E_{(\ell-1)ij}^{km}$ considered in terms of the number $I_{\ell i}$ of elements $E_{(\ell-1)ij} \subset E_{(\ell-1)i}$ and the dimensions of their vector variables; increasing $E_{(\ell-1)i}$ complexity requires increased degree of time-sharing (time-multiplexing) by $Sw_{\ell i}$ which will tend to result in decreased sampling frequencies.

4) The general characteristics of the inputs (desired outputs) of $S'_{\ell i}$ such as their amplitudes and tolerance limits; eg., increasing resource deployment and resource deployment rates tend to increase the corresponding sampling rates partly as a result of increasing error "costs" resulting from an increase in $ resources being deployed (see #6 below). On the other hand, increasing tolerance limits or discretionary limits (these will be defined and analyzed later in some detail) lead almost inevitably to decreased sampling rates. One of the objectives of increasing these limits by $rI_{\ell i}$ is, in fact, to reduce his need of attending to low-priority or low-risk closed-loop control functions and thus rely more on open-loop control.

5) The "cost" associated with sampling; increasing sampling cost

tends to reduce sampling frequency.

6) The "cost" associated with errors between the actual and planned $E^{km}_{(\ell-1)ij}$ outputs; increasing error costs tend to increase sampling frequency.

7) The reliability of the system $E^{km}_{(\ell-1)ij}$, i.e., the probability of $E^{\cdot\cdot}_{\cdot\cdot\cdot}$ performing adequately for the time period scheduled for its completion, adequately in the sense that the output variables of $E^{\cdot\cdot}_{\cdot\cdot\cdot}$ remain within their tolerance or discretion limits. In general, increasing reliability causes decreasing sampling frequencies.

8) $rI_{\ell i}$'s view of the supervisory process; some supervisors simply believe in checking their subordinates more frequently than do others just as some individuals prefer to be more closely supervised than others.

9) The value of ℓ; generally, sampling frequency decreases with increasing ℓ.

In addition to the above factors influencing the sampling behavior of $Sw_{\ell i}$, various standard and centralized information systems for data acquisition, storage, processing, retrieval, display and transmission may also partly determine the instants and rates of information feedback to the controller $C_{\ell i}$. The receptor $R_{\ell i}$ is an element of this composite information system, which quite typically outputs periodic data such as accumulated monthly cost data. There are generally significant delays associated with such systems so that $R_{\ell i}$ may have to incorporate a delay element. Thus, for example, total cost data for $E^{km}_{(\ell-1)ij}$ covering one full month may not be available to $rI_{\ell i}$ until the 5-th day of the next month.

Another not untypical factor influencing the properties of the sampling-function matrix $U^{\cdot\cdot}_{\cdot\cdot\cdot}$ and one which has been increasingly promoted during recent years, is the idea of exception reporting [1]. This concept is the basis of the so-called management by exception which philosophy is similar to the idea of limit comparison and alarm utilized in computerized process control wherein only exceptional operating conditions are brought to the operator's attention. The idea is, of course, typical to most quality control systems. It may be incorporated into our management control system $S'_{\ell i}$ through the inclusion of a threshold or limit (upper and/or lower) detector in $R_{\ell i}$ which causes the sampler $Sw_{\ell i}$ to close whenever these limits are exceeded by their corresponding controlled variables.

2.4.2 A Proposed Controller Logic Flow Chart

2.4.2.1 The Fast-Time Internal Model

Because of the planning ahead function of $P_{\ell i}$, the controller $C_{\ell i}$ possesses predictive information about the performance requirements of the control system $S'_{\ell i}$. That is, $C_{\ell i}$ knows with some accuracy the desired values to be assumed by the output functions of $S'_{\ell i}$ throughout their effective future time domains. The planner $P_{\ell i}$ may arrive at such predictive $S'_{\ell i}$ input in a number of ways. Various programming and network techniques such as PERT and CPM are potential mathematical tools. Computer simulation based on a mathematical model of the transfer characteristics of the system $S'_{\ell i}$ and its component systems is another planning aide. Whatever systems engineering tools are being used, if any, the essential information required to translate higher-level plans and direct control inputs to $P_{\ell i}$ into goals, intended performance and structure of the system $S'_{\ell i}$ is generated by a conceptual model of the structure and behavior range of $S'_{\ell i}$. In these terms, the output of $P_{\ell i}$ is partly the result of the role incumbent $rI_{\ell i}$ performing mental simulations on an internal model "of the entire situation from the assumed point of view of the subordinate" ([46], p. 91) or more generally, a model of $S'_{\ell i}$ including $rI_{\ell i}$'s own control options. The internal-model idea, which is felt to be central to human learning and decision making, will be elaborated on in this and the next two sections as we shall attempt to develop a logic flow chart for a general organizational controller.

Consider in particular the input of $S'^{km}_{\ell i} \subset S'_{\ell i}$ that is the planned or desired response of the effector $E^{km}_{(\ell-1)ij}$ assumed to perform one distinct task. According to the preceding, this input is known to $C_{\ell i}$ or more specifically to $C^{km}_{\ell i}$ for some future time interval. Once $C_{\ell i}$ is presented with such performance requirements for $E^{km}_{(\ell-1)ij}$, the next step is for $C_{\ell i}$ to determine the control or command input to $E^{km}_{(\ell-1)ij}$ that will bring about this desired control system performance. Such an initial control action obviously has to be arrived at on the basis of an open-loop strategy. This is where the idea of an internal model enters into our organizational control system formulation. It is based on the premise that the role incumbent $rI_{\ell i}$ possesses an internal model or mental image of the structure and behavior of the subsystem (effector) he is controlling. In terms of this model, the control function $C_{\ell i}$ of $rI_{\ell i}$ decides on the initial control action for $E^{km}_{(\ell-1)ij}$, which is presumably optimal in some sense, by what amounts to mental trial and error explorations of alternative control actions applied to such a model of $E^{km}_{(\ell-1)ij}$.

By considering that such mental simulations are performed on fast-time internal models of their real-time modelled organizational systems, we essentially extend the idea of a so-called Ziebolz type automatic controller [50] and Kelley's level-1 predictive controller (in manual tracking) [29] into an organizational control setting. Particular to both of these types of controllers is a fast-time model of the controlled element or effector. As the name implies, a fast-time system operates on an accelerated time scale relative to the real-time system it is modelling. Thus, generally speaking, the response of the fast-time analog of the real-time $E^{km}_{(\ell-1)ij}$ to some control input on an accelerated time scale αt is identical to the response of $E^{km}_{(\ell-1)ij}$ to the same input on a real time scale t except that the former is α times faster.*

Once the optimal control input to $E^{km}_{(\ell-1)ij}$ has been determined by making repetitive "dry runs" on its fast-time model $E^{\cdot km}_{(\ell-1)ij}$, this control action is communicated to $rI_{(\ell-1)ij}$ or, in model terms, to $E^{km}_{(\ell-1)ij}$ as a direct input to the planning system $P^{km}_{(\ell-1)ij}$. This initial command input is generally specified for some fixed interval

$$I^{km}_{t(\ell-1)ij} = \left\{t : t^{km}_{a(\ell-1)ij} \leq t \leq t^{km}_{t(\ell-1)ij}\right\}$$

where $t^{\cdot\cdot}_{a\cdot\cdot}$ and $t^{\cdot\cdot}_{t\cdot\cdot}$ denote, respectively, the allocation and targeted completion points for the task associated with $E^{km}_{(\ell-1)ij}$. The length of this interval is a fundamental parameter of the time-span of discretion model to be developed subsequently.

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*Mathematically, a fast-time model may be defined as follows: let S and $S^{\cdot}$ be some systems for which generically

$$\bar{y}(t) = S\left[\bar{x}(t)\right] \quad \text{and} \quad \bar{y}^{\cdot}(t) = S^{\cdot}\left[\bar{x}^{\cdot}(t)\right]$$

and where the inputs $\bar{x}(t)$ and $\bar{x}^{\cdot}(t)$ start at $t=t_0$. Then, $S^{\cdot}$ is a fast-time model of real-time S if and only if

$$\bar{x}^{\cdot}(t) = \bar{x}(at - t_0(a-1)) \Longrightarrow \bar{y}^{\cdot}(t) = \bar{y}(at - t_0(a-1))$$

or equivalently, iff

$$\bar{x}(t) = \bar{x}^{\cdot}(\tfrac{1}{a}t + \tfrac{1}{a}t_0(a-1)) \Longrightarrow \bar{y}(t) = \bar{y}^{\cdot}(\tfrac{1}{a}t + \tfrac{1}{a}t_0(a-1))$$

where $\Longrightarrow$ denotes "implies that" and the letter a is the scale or relative speed factor, $S^{\cdot}$ being a times as "fast" as S.

This definition clearly does not imply that $S^{\cdot}$ is an exact dynamic replica of S. However, the general form of their transfer characteristics are the same. If, for example, $x(t)$ and $y(t)$ are related through a second-order linear differential equation whose natural angular frequency is w_n and damping ratio ξ. Then, the second-order differential equation between $x^{\cdot}(t)$ and $y^{\cdot}(t)$ has a natural frequency equal to aw_n but the damping ratio is still ξ.

2.4.2.2 The Iterative Nature of Planning and Control

The preliminary input to $E^{km}_{(\ell-1)ij}$ is frequently of a tentative nature and may subsequently be changed during the interval $I^{km}_{t(\ell-1)ij}$ because of two main reasons. Firstly, the input to the planning system $P_{\ell i}$ may be changed since, as will be touched on briefly below, higher-level plans may be revised. Secondly, feedback information may reveal significant discrepancies between the actual and desired performance of $E^{km}_{(\ell-1)ij}$. We shall start off by analyzing the latter case. Rather than concentrating further on the system $E^{km}_{(\ell-1)ij}$ in isolation from the remaining level-(ℓ-1) component effectors of $E_{(\ell-1)i}$ and thereby ignoring various possible significant interactions, the subsequent development of the interior controller flow chart will focus on the composite systems $C_{\ell i}$ and $E_{(\ell-1)i}$.

Whenever the controller $C_{\ell i}$ receives feedback information about the true output of $E_{(\ell-1)i}$, which, according to the analysis of a previous section is generally of a sampled-data nature, the comparator or summing junction (6) (see Fig. 6, p.55) compares the actual with the desired output of $E_{(\ell-1)i}$. Only a subset of the total $C_{\ell i}$ input and $E_{(\ell-1)i}$ output may enter into such a comparison at a given instant such as those associated with $E^{km}_{(\ell-1)ij}$. If a discrepancy between actual and desired performance is detected, a logic element (7) decides on whether or not standing control actions may have to be changed. If it is decided that such changes may be warranted, then alternative control actions are generated (1) and tried on a fast-time model $E^{*}_{(\ell-1)i}$ of $E_{(\ell-1)i}$ (3). The "predicted" response of $E^{*}_{(\ell-1)i}$ is combined (4) with historical information about the corresponding output variables of $E_{(\ell-1)i}$ (14) and compared (6) with the past, present and future values of the pertinent control system input variables (5). The result of this comparison is then evaluated (7). If, on the basis of some error performance quality criterion, the new control actions are determined to be optimal, they are then communicated (8) to $E_{(\ell-1)i}$ or perhaps to $E^{km}_{(\ell-1)ij}$ in particular. If they are not optimal, another set of control actions are tried on $E^{\cdot}_{(\ell-1)i}$ and the above cycle is repeated until a set of optimal control actions are selected.

The criterion or index of control system performance quality employed by the logic element (7) always incorporates, in addition to deviation (error) between actual and desired accomplishment or some function thereof, the control input to $E_{(\ell-1)i}$ and hence to $E^{\cdot}_{(\ell-1)i}$ primarily in terms of constraints. We are thus proposing that the optimal control inputs are essentially arrived at by a search technique involving a fast-time effector model and constrained minimization of a performance quality index.* Such constraints are, for example, (i) the role incumbent $rI_{(\ell-1)ij}$ works 8 hrs./day and 5 days/week by union contract constraining the progressive degree of project completion variable and (ii) a machine operated by $rI_{(\ell-1)ij}$ and providing items for inventory storage has a limited production capacity constraining the quantity variable that $rI_{\ell i}$ has to determine in order to compensate for understorage and projected sales volume.

Even though some control inputs to $E_{(\ell-1)i}$ arrived at by the above "fast-time search-for-control actions" technique may be the best ones for the corresponding control system inputs and control action constraints, the pertinent anticipated deviations between planned and true

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*We do not, of course, want to imply that such constrained minimization is a mathematical operation. A human role incumbent rarely performs optimally in a mathematical sense.

performance of $E_{(\ell-1)i}$ may still be quite significant, perhaps unacceptably so. Thus, for example, the role incumbent $rI_{(\ell-1)ij}$ may be assigned full-time to a maximum priority operation. However, the expected progressive degree of completion of the operation may still fall below what was planned to the extent that the project would be completed significantly later than scheduled. The only recourse open to $rI_{\ell i}$ and in particular to his control function $C_{\ell i}$ may be to call for a change in the appropriate $C_{\ell i}$ inputs. This involves replanning on behalf of $rI_{\ell i}$ as is incorporated in the controller flow chart of Fig. 6 (p.55) through the logic element (9). The requisite replanning may be accomplished by $rI_{\ell i}$'s own planning system $P_{\ell i}$ or it may ultimately require higher-level plans and control instructions to be changed.

The need for higher-level plans and control actions to be changed is not infrequently brought about by failure of higher-level planners and controllers to realize in advance the detailed ramifications of their decisions. In order to offset the potential high cost or loss that may be incurred if lower-level systems slavishly follow such higher-level plans and control instructions and try to perform their individual operations optimally, many organizations have built into their information systems iterative schemes that are unbiased against the above type of upward flow of information proposing changes in higher-level decisions.

2.4.2.3 Controller Adaptive Characteristics

The human controller is considered to be a highly complex and perfected adaptive system. It is his ability to change his control behavior adaptively in the face of changing controller input characteristics (input adaptation), effector dynamics (effector, plant or task adaptation) and control experience (learning or skill acquisition) which makes for the versatility of a human controller.* Of these three types of adaptation, we shall mainly consider, though somewhat superficially, effector adaptation within our general level-ℓ organizational control system $S'_{\ell i}$.

The basic objective of such adaptation is for $rI_{\ell i}$ or, more precisely, his control function $C_{\ell i}$ to respond to disturbances acting on $E_{(\ell-1)i}$ by making appropriate changes in the control strategy. Such disturbances which, from the point of view of $C_{\ell i}$, change the dynamics of $E_{(\ell-1)i}$, may be both external (eg., national economy, consumer behavior, government and union regulations, weather, competition, etc.) and internal (equipment wear and failure, employee sickness, absenteeism, strikes, etc.) to $E_{(\ell-1)i}$. In the external disturbance input or load, we shall include possible interactions between other component effectors of the total OPFCS S_L as analyzed above.

It is an essential function of any organizational control system to recognize such disturbances and adjust its control behavior so as to maintain optimal performance quality in spite of the disturbances. A basic management problem is that the sources of these disturbances are not always obvious and those that are may produce disturbances which are difficult to measure and predict partly because of their usually random nature. Similarly, their initial occurrence or time origins may not be known in advance. As far as possible, a manager attempts, or should attempt, to use available information to anticipate such disturbances and their effect on the output and behavior of the

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*A good analysis of these three types of adaptation is presented by Young and Stark [52]. Their analysis is directly concerned with simple level-(ℓ=1) manual tracking systems.

system he is controlling.

In order to incorporate this concept of adaptation into our model, we shall propose an extension to the present state of our controller flow chart. In particular, the process whereby information is obtained and adaptive decisions made needs to be considered. We shall approach the problem by elaborating on the idea of an internal effector model which also underlies the so-called "model-reference" adaptive control system for compensatory manual tracking developed by Young and Stark [52]. Thus, we are proposing that whenever $rI_{\ell i}$ via his control element $C_{\ell i}$ receives (partial) feedback information about the actual output of $E_{(\ell-1)i}$, two things generally take place. Firstly, and as discussed previously, this output is compared with its planned or desired output and, if warranted, corrective actions are taken by making repetitive "dry runs" on a fast-time internal model $E^{*}_{(\ell-1)i}$ of $E_{(\ell-1)i}$. Secondly, this feedback is compared with what $C_{\ell i}$ expected it to be on the basis of its control input to $E_{(\ell-1)i}$ being applied to $E^{*}_{(\ell-1)i}$. The generation of this expected (predicted) response is illustrated in our flow chart of Fig. 6 (p.55) by the switch (2) being moved to position #2. The corresponding output (#2) is stored (12) and its data points relevant to feedback samples of the $E_{(\ell-1)i}$ output are retrieved for comparing the two sets of data (13). If their deviations exceed some threshold (15), this signals that $E^{*}_{(\ell-1)i}$ is not a proper model of $E_{(\ell-1)i}$ because the environmental and internal disturbances acting on $E_{(\ell-1)i}$ have not been sufficiently accounted for. The adaptive logic (16) is then called upon to rectify these discrepancies to avoid control degradation when $E^{*}_{(\ell-1)i}$ may subsequently be used for arriving at new control actions.

Little is known about the underlying cognitive process performed by the adaptive operator or "adaptor" (16) and our present objective falls considerably short of making any significant headway in this area. The process itself is central to "organizational learning" and its function is to employ available information for improving the accuracy or fidelity of $E^*_{(\ell-1)i}$ so that the expected response of $E_{(\ell-1)i}$ agrees with its true response. An essential problem here is to diagnose the cause of the deviation between these two responses. We propose that, according to typical human behavior, the diagnostic problem is approached by means of a trial-and-error or reinforcement strategy aided by information about the $E_{(\ell-1)i}$ disturbances. That is, the control actions which resulted in the deviations are again tried (11) on $E^*_{(\ell-1)i}$ but the dynamics of $E^*_{(\ell-1)i}$ is altered in accord with available information applying to $E_{(\ell-1)i}$. If deviations still persist, these control actions are again imposed on a further modified internal control situation. This cyclic procedure may finally result in an internal model of $E_{(\ell-1)i}$ that sufficiently incorporates changing transfer characteristics of $E_{(\ell-1)i}$ so that the deviations between $E_{(\ell-1)i}$'s expected and actual output are at acceptable levels. If not, the resulting conception of $E_{(\ell-1)i}$ may be accepted as tentative until further feedback information may allow more accurate modelling.

In the preceding two paragraphs we considered essentially what may be termed "non-anticipatory" adaptation under which adaptive control changes are made when or after performance feedback from $E_{(\ell-1)i}$ reveals adaptive requirements. Alternatively, "anticipatory" effector adaptation may occur under which the requisite information is obtained by the adaptor (16) and adaptive control changes made before the corresponding changes in the dynamics of $E_{(\ell-1)i}$ take place. These a priori $E_{(\ell-1)i}$ changes are incorporated into the dynamics of $E^{*}_{(\ell-1)i}$ and alternative control actions for $E_{(\ell-1)i}$ are generated (1) and tried on $E^{*}_{(\ell-1)i}$ on an iterative basis. As discussed earlier, those control actions are finally selected that would appear to maintain optimal control system performance quality in spite of anticipated behavioral changes for $E_{(\ell-1)i}$. In this way, adaption is being brought about before control is being negatively affected by changes in the control situation.

Case Study

To illustrate the preceding adaptive concepts, consider some foreman rI_{2i} in charge of a group of shopfloor workers $\{rI_{1ij}\ ;\ j \epsilon I_{2i}\}$ each responsible for minor manufacturing, machining and assembly jobs within their areas of specialization. One individual rI_{1ij} was simultaneously responsible for (i) the machining of 50 metal shafts with specified diameter 5" ± 0.01" and a prescribed surface finish and (ii) the assembly of some piece of equipment, each task of which has a planned operation time of some 2 weeks. Shortly after these operations had started, rI_{2i} was informed by the purchasing department that one component ordered for the assembly was not available. The foreman rI_{2i} then incorporated this advance disturbance information (the component in question would not be required until towards the end of the assembly task) into his conception of the relevant effector situation and mentally tried out alternative control strategies to properly compensate for this disturbance. He finally concluded that the best he could do was to have rI_{1ij} carry on with the assembly up to the point where the lacking component would be needed and then complete the assembly when some other role incumbent rI_{1ij}, had completed the machining of this component. In this way, the assembly was completed in the originally scheduled time and rI_{1ij}, was only temporarily taken off a low-priority task to produce the lacking component.

Similarly, the task of machining the 50 shafts turned out to be subject to a disturbance (internal). However, in this case the disturbance was not anticipated in advance. The role incumbent rI_{1ij}, being a highly skilled lathe operator, knew "by heart" the relationship between the degrees of rotation of the handwheel* and the depth of cut. The screw of this old engine lathe had a considerable backlash to which rI_{1ij} had continuously adapted during the years. After having relied on his own feel for the setting of the last cut of the first shaft, he found that, after a length of a few inches had been cut, the measured diameter fell considerably short of the lower tolerance limit. He then tried to determine the cause of this discrepency between the measured diameter of 4.98" and what he had expected to be about 5.00". He finally concluded that the backlash he had become used to was only significant when cutting shafts of larger that 5" diameter since that was what the lathe had been primarily used for. The female thread was thus hardly worn towards the end.

Once this disturbance had been detected and incorporated into rI_{1ij}'s model of his control situation, the 50 shafts were all produced to the required standards. Furthermore, the adaptive change was made sufficiently quickly so that the disturbance did not affect the next

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*The handwheel is connected to the screw which, upon being turned, moves the cross-slide with the cutting tool perpendicularly to the rotating work piece.

higher control system. Had it been more serious so that rI_{1ij} was unable to compensate for it, then it might have required rI_{2i} to respond to it. Had it been decided that a new machine was perhaps required, even higher-level systems would have been involved.

While these proposed adaptive characteristics of an organizational controller have been presented quite generally and rather briefly, we feel that our effort represents a first step in the direction of developing a realistic logic flow chart of an organizational controller that incorporates effector adaptation. The adaptive process itself is central to organizational control yet is a process about which little is still known even for relatively simple human control tasks. There is certainly a great need for further research into human adaptive behavior if we are even to approach a complete understanding of the complex control modes of organizational control systems. We hope to make some further contributions to this end during our projected future research.

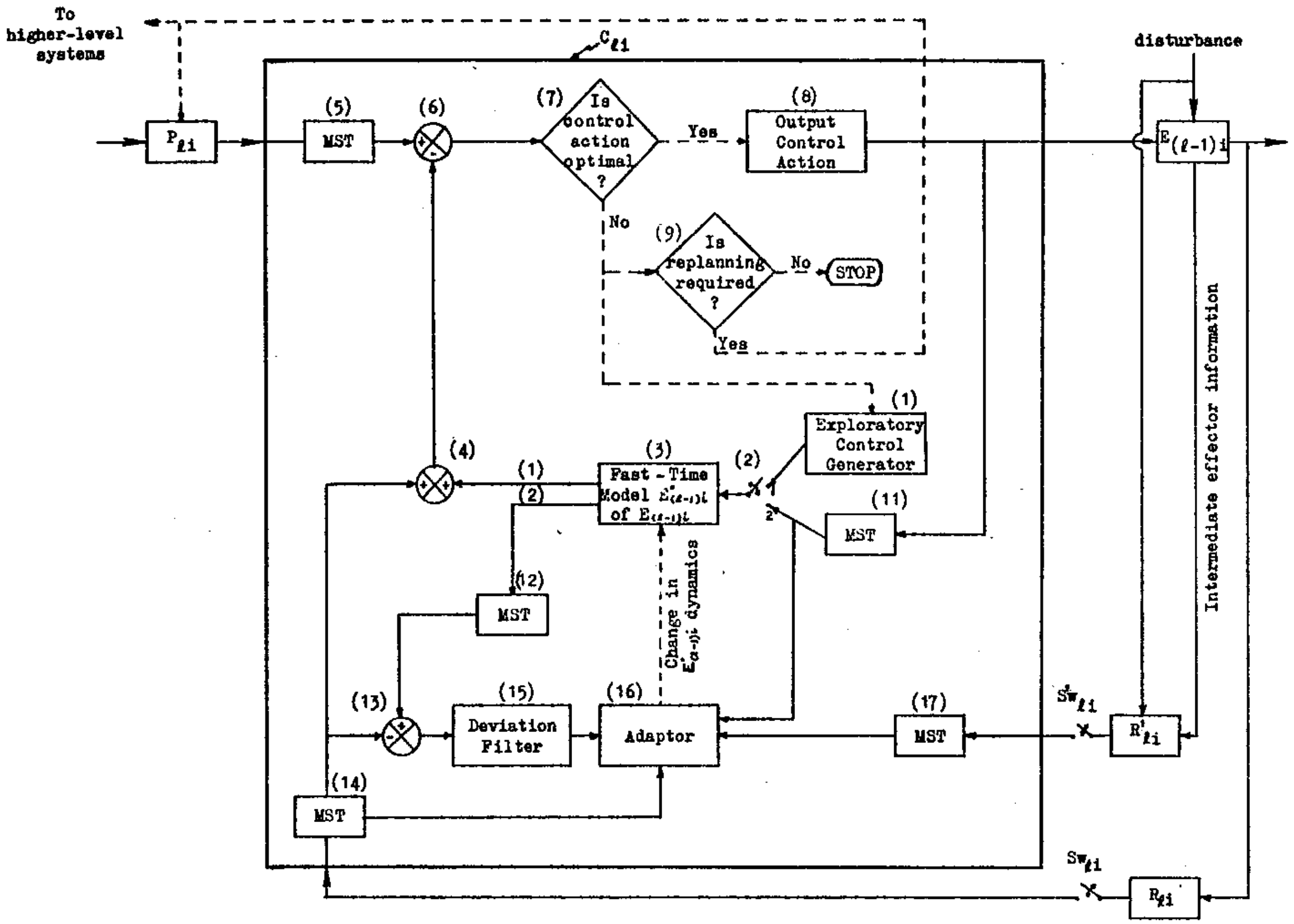

FIG. 6: CONTROLLER FLOW CHART FOR LEVEL-ℓ OPFCS INCORPORATING ADAPTATION AND FAST-TIME EFFECTOR MODEL PREDICTIONS
(MST = Memory Storage & Retrieval)

3. TIME-SPAN OF DISCRETION

3.1 Introductory Comments

The time-span of discretion (TSD) concepts developed by Elliott Jaques were briefly introduced in section 1.2 above and reference was made to the work done by other researchers in this area. It is the objective of the remainder of this dissertation to analyze the basic TSD concepts within the framework of the general organizational planning and feedback control model developed above. The TSD ideas relating directly to Jaques' estimators for level of work (LOW) will be formulated mathematically.

The LOW estimators will be subjected to an in-depth critical evaluation on a theoretical basis supported by detailed empirical TSD data. Because of the scarcity of such data, a detailed account of our own considerable amount of field data will be presented. These data together with descriptions of the physical processes involved, particularly in one of the firms studied, should provide for a fairly comprehensive picture of the structure and general function of the total organizational system and its component elements

3.2 Basic TSD Concepts

Whenever the role incumbent $rI_{\ell i}$ assigns some task $S^{km}_{(\ell-1)ij}$ to his subordinate $rI_{(\ell-1)ij}$, $rI_{(\ell-1)ij}$ is generally called upon to exercise some discretion within certain prescribed limits. The discretionary task content permits and requires $rI_{(\ell-1)ij}$ to use his own judgement while performing the task whereas prescriptions or the prescribed task content guides and constrains such freedom of judgement. The discretion associated with $S^{km}_{(\ell-1)ij}$ manifests itself in the degree of flexibility of both the performance requirements of $E^{km}_{(\ell-1)ij}$ and hence of $S^{km}_{(\ell-1)ij}$ and the control inputs to $S^{km}_{(\ell-1)ij}$. These functions of time are permitted to assume values falling between upper and/or lower tolerance limits which in turn enclose the "discretion regions" of $S^{km}_{(\ell-1)ij}$.

Thus, for $S^{km}_{(\ell-1)ij}$, which is allocated by $rI_{\ell i}$ at $t=t^{km}_{a(\ell-1)ij}$ and targeted for completion by $t=t^{km}_{t(\ell-1)ij}$, the quality variable is typically specified (explicitly or implicitly) in terms of quality control limits. The progressive degree of completion variable may be formulated such that (i) $rI_{(\ell-1)ij}$ may himself determine when to attend to this task just as long as it is completed by $t=t^{km}_{t(\ell-1)ij}$ (maximum discretion w.r.t. this attribute), (ii) $rI_{(\ell-1)ij}$ is required to devote all his time to $S^{km}_{(\ell-1)ij}$ during $I^{km}_{t(\ell-1)ij} = \left[t^{km}_{a(\ell-1)ij}, t^{km}_{t(\ell-1)ij}\right]$ so that his discretion here is limited to $rI_{(\ell-1)ij}$ partly determining his own pace or activity level or (iii) it represents a case intermediate to the extremes of (i) and (ii). Other variables are similarly specified, eg., resource deployment for $S^{km}_{(\ell-1)ij}$ has some upper limit, etc.

If $rI_{(\ell-1)ij}$ should perform the task $S^{km}_{(\ell-1)ij}$ substandardly, i.e., if any of the output variables or intermediate variables of $S^{km}_{(\ell-1)ij}$ should assume values outside their prescribed limits, then this may be detected by $rI_{\ell i}$ or more precisely by the controller $C_{\ell i}$ through the informational feedback process analyzed above. The sampling frequencies of the samplers $Sw_{\ell i}$ and $S'w_{\ell i}$ relevant to $S^{km}_{(\ell-1)ij}$ depend on, in addition to the factors discussed previously (for $Sw_{\ell i}$ in particular but also partly applicable to $S'w_{\ell i}$), the "amount" of discretionary content for $S^{km}_{(\ell-1)ij}$. Our own field data generally support the rather obvious hypothesis that there exists a direct relationship between the feedback sampling frequency and discretionary content.

From the TSD point of view, however, the primary interest lies in the length of the intervals between $t^{km}_{a(\ell-1)ij}$ and the final sampling points rather than in the above sampling frequencies or inter-sample interval lengths. These final sample points or <u>review points</u> represent the points beyond which the continuous exercise of marginally substandard discretion by $rI_{(\ell-1)ij}$ on $S^{km}_{(\ell-1)ij}$ would not remain undetected by $rI_{\ell i}$. Such exercise of substandard discretion may and under some circumstances would of course be detected by $rI_{\ell i}$ at the intermediate sampling points. However, it could not go undetected beyond the review points. Thus, during the intervals between $t^{km}_{a(\ell-1)ij}$ and the review points for quality, progressive degree of completion (or timing), resource deployment, etc., $rI_{(\ell-1)ij}$ may possibly exercise substandard discretion w.r.t. these system attributes without $rI_{\ell i}$ necessarily being aware of it.

For the sake of notational simplicity, our subsequent formalization of the TSD concepts will primarily be in terms of $S^{km}_{\ell i}$ rather than $S^{km}_{(\ell-1)ij}$. Thus, for the task $S^{km}_{\ell i}$ whose allocation point is $t^{km}_{a\ell i}$, we shall let $t^{km}_{q\ell i}$ and $t^{km}_{t\ell i}$ denote, respectively, the quality review instant and timing review instant or targeted completion point (quality and timing or progressive degree of project completion are the particular system properties considered by Jaques). The point $t^{km}_{t\ell i}$ may, of course, be different from the actual completion point $t^{km}_{\ell i}$ for the task $S^{km}_{\ell i}$. Furthermore, let $I^{km}_{\ell i}$, $I^{km}_{t\ell i}$ and $I^{km}_{q\ell i}$ denote the following intervals as well as their lengths:

$$I^{km}_{\ell i} = \left\{t: t^{km}_{a\ell i} \leqslant t \leqslant t^{km}_{\ell i}\right\}$$

$$I^{km}_{t\ell i} = \left\{t: t^{km}_{a\ell i} \leqslant t \leqslant t^{km}_{t\ell i}\right\}$$

$$I^{km}_{q\ell i} = \left\{t: t^{km}_{a\ell i} \leqslant t \leqslant t^{km}_{q\ell i}\right\}$$

where k and m are particular points of the index sets $K_{\ell i}$ and $M^{k}_{\ell i}$ of sec. (2.2.3.3). If $T_{\ell i}$ denotes the previously introduced analysis interval or "TSD-window"

$$T_{\ell i} = \left\{t: t_{0\ell i} \leqslant t \leqslant t_{1\ell i}\right\}$$

as well as its width, then, for all $k \in K_{\ell i}$ and $M \in M^{k}_{\ell i}$ it is required that either $t^{km}_{a\ell i} \in T_{\ell i}$ or $t^{km}_{\ell i} \in T_{\ell i}$. It will generally be considered that $t = t_{1\ell i}$ corresponds to the "instant" at which the TSD analysis of the role $r_{\ell i}$ was made although this needs not necessarily be so. The time origin $t=0$ may be left unspecified.

This mathematical symbolism may now conveniently be used to introduce the following concepts of Jaques' theory:

1. The role $r_{\ell i}$ or, if we like, the system $S_{\ell i}$ is <u>multi-task</u> if $I^{km}_{\ell i} \cap I^{k'm'}_{\ell i} \neq \emptyset$ for any (k,m,k',m')[*] where possibly $k=k'$ or $m=m'$, $\emptyset$ denotes the empty or null set $\left\{t: t \neq t\right\}$;

   otherwise, $r_{\ell i}$ is <u>single-task</u>.
2. $S^{km}_{\ell i}$ is <u>intermittent</u> if $I^{km}_{\ell i} \cap I^{k'm'}_{\ell i} \neq \emptyset$ for any (k',m');

   otherwise, $S^{km}_{\ell i}$ is <u>continuous</u>.

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[*] Whenever we use "any (k,m)" or "all (k,m)" etc., this is only shorthand for "any $k \in K_{\ell i}$ and $m \in M^{k}_{\ell i}$" or "all $k \in K_{\ell i}$ and $m \in M^{k}_{\ell i}$".

3. The TSD of $S_{\ell i}^{km}$ is given by

$$T_{\ell i}^{km} = \max\left\{I_{t\ell i}^{km}, I_{q\ell i}^{km}\right\} = \begin{cases} I_{t\ell i}^{km} \text{ if } r_{\ell i} \text{ is multi-task} \\ I_{q\ell i}^{km} \text{ if } r_{\ell i} \text{ is single-task} \end{cases} \qquad (3.1)$$

The TSD of $S_{\ell i}^{km}$ is then the longest interval during which $rI_{\ell i}$ may exercise his own discretion while carrying out the task $S_{\ell i}^{km}$ without being subjected to supervisory review. If $r_{\ell i}$ is multi-task, which according to Jaques' as well as our own empirical findings is by far the most predominant of the two role types, then $T_{\ell i}^{km}$ may be given an interesting alternative interpretation from the system $S_{\ell i}^{km}$. In this case, $T_{\ell i}^{km}$ is the anticipation or preview span of the anticipatory (non-causal) $S_{\ell i}^{km}$. In terms of the planning system $P_{\ell i}^{km} \in S_{\ell i}^{km}$ whose planning horizon is $t = t_{t\ell i}^{km}$, $T_{\ell i}^{km}$ is simply its planning span. That is, $T_{\ell i}^{km}$ is the ultimate time frame or window within which the level-$(\ell+1)$ control commands are translated into level-ℓ operating plans which in turn the control system $S_{\ell i}^{\prime km} \subset S_{\ell i}^{km}$ is designed to accomplish.

Both the planning and control decisions made by $rI_{\ell i}$ (or $P_{\ell i}^{km}, C_{\ell i}^{km}$) involve an uncertain future. Such uncertainty is primarily due to the fact that $rI_{\ell i}$ or $C_{\ell i}^{km}$ may not be entirely certain as to how the effector he is directly controlling is going to respond to its control actions. That is, $rI_{\ell i}$'s internal model of the dynamics of this effector (as well as of possible alternative effectors considered during the $P_{\ell i}^{km}$ operation) is of limited accuracy caused in main by effector disturbances (external and internal) not properly anticipated by $rI_{\ell i}$. This limited model accuracy or fidelity is one of the principal reasons for $rI_{\ell i}$ (or $C_{\ell i}^{km}, P_{\ell i}^{km}$) allocating discretionary limits to the effector control input as well as to the $C_{\ell i}^{km}$ input. Similarly, the "amount" of discretion allocated to $rI_{\ell i}$ himself is related to what $rI_{\ell i}$'s superior feels to be the precision of his internal model of $S^{km}_{\ell i}$.

All actions taken by $rI_{\ell i}$ (or $P^{km}_{\ell i}, C^{km}_{\ell i}$) throughout the TSD interval $T^{km}_{\ell i}$ are the results of decision making under such uncertainty. Whether or not these actions resulted in the marginal substandard exercise of discretion by $rI_{\ell i}$ (or $S^{km}_{\ell i}$) may not be completely known by his supervisor until the end of the $T^{km}_{\ell i}$ interval. Jaques postulates that it is the psychological stress resulting from this uncertainty over time which determines the "size" of a task $S^{km}_{\ell i}$ as felt by the individual or the system directly responsible for executing it. The size of the total job performed by $rI_{\ell i}$ is then, according to Jaques, determined by the longest time interval across all tasks during which $rI_{\ell i}$ is subjected to such uncertainty without supervisory review of his discretion being exercised. Based on this proposition, Jaques suggests an estimate for the true LOW, $L_{\ell i}$, allocated into the role $r_{\ell i}$ (performed by $rI_{\ell i}$ or the composite system $S_{\ell i}$) during the interval $T_{\ell i}$, which may be defined as follows:

4a. If $r_{\ell i}$ is multi-task or single-task with $t^{km}_{q\ell i} = t^{km}_{t\ell i}$ for all (k,m), then

$$\hat{L}_{\ell i} = \max_{(k,m)}\left\{T^{km}_{\ell i}\right\} = \max_{(k)}\left\{T^{k}_{\ell i\max}\right\} \qquad (3.2)$$

i.e., the LOW estimate is equal to the TSD for the task(s) achieving the largest TSD among all members of $S^{km}_{\ell i}$ during $T_{\ell i}$.*

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*See footnote on following page.

4b. If (i) $r_{\ell i}$ is single-task with $t^{km}_{q\ell i} > t^{km}_{t\ell i}$ for some (k,m), (ii) $T^{kmk'm'}_{\ell i} \triangleq t^{km}_{q\ell i} - t^{k'm'}_{a\ell i}$ where possibly $k'=k$, $m'=m$, and (iii) there is no set $I^{k''m''}_{q\ell i} \subset I^{kmk'm'}_{q\ell i} \triangleq \left\{t: t^{k'm'}_{a\ell i} \leq t \leq t^{km}_{q\ell i}\right\}$ where $k'' \neq k,k'$ and $m'' \neq m,m'$, then

$$\hat{\hat{L}}_{\ell i} = \max_{(k,m,k',m')} \left\{T^{kmk'm'}_{\ell i}\right\} \tag{3.3}$$

i.e., the LOW estimate is equal to the TSD for the "task sequence(s)" achieving the largest TSD among all task sequences formed by members of $\left\{S^{km}_{\ell i}\right\}$ during $T_{\ell i}$ (see Fig. 7 below).

If Fig. 7 is approximately drawn to scale and if the excluded tasks would not alter the LOW estimates, then it is seen that $\left\{S^{32}_{\ell i}, S^{12}_{\ell i}, S^{21}_{\ell i}\right\}$ constitutes the task sequence with maximum TSD. The task set $\left\{S^{12}_{\ell i}, S^{21}_{\ell i}\right\}$ forms a task sequence with the second largest TSD. For this role it then follows from eq.(3.3) that $\hat{\hat{L}}_{\ell i} = T^{3221}_{\ell i}$.

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[*] See reference on preceding page.
Jaques' use of "extended tasks" for multi-task $r_{\ell i}$ is entirely redundant in the last LOW estimation approach outlined in his <u>Time-Span Handbook</u> and only complicates matters unnecessarily. It is easy to show mathematically that the LOW estimates are unaffected by whether we consider "ordinary" tasks, as we are doing, or extended tasks.

<u>Proof</u>:
In terms of our symbolism, a task $S^{k'm'}_{\ell i} \in \left\{S^{km}_{\ell i}; k \in K_{\ell i}, m \in M^{k}_{\ell i}\right\} \triangleq \left\{S^{km}_{\ell i}\right\}$ is said to be extended if there does not exist any other task $S^{k''m''}_{\ell i} \in \left\{S^{km}_{\ell i}\right\}$ such that $I^{k'm'}_{t\ell i} \subset I^{k''m''}_{t\ell i}$. Let $K'_{\ell i}$, $M'^{k}_{\ell i}$ and $K''_{\ell i}$, $M''^{k}_{\ell i}$ denote, respectively, the index sets corresponding to the extended and non-extended tasks. Then, from eq.(3.2) it follows that

$$\hat{L}_{\ell i} = \max_{\substack{k \in K_{\ell i} \\ m \in M^{k}_{\ell i}}} \left\{T^{km}_{\ell i}\right\} = \max_{\substack{k \in (K'_{\ell i} \cup K''_{\ell i}) \\ m \in (M'^{k}_{\ell i} \cup M''^{k}_{\ell i})}} \left\{T^{km}_{\ell i}\right\} = \max_{\substack{k \in K'_{\ell i} \\ m \in M'^{k}_{\ell i}}} \left\{T^{km}_{\ell i}\right\}$$

where the last equality follows from the fact that, according to the definition given of an extended task, for any $T^{k''m''}_{\ell i} \in \left\{T^{km}_{\ell i}; k \in K''_{\ell i}, m \in M''^{k}_{\ell i}\right\}$ there is at least one $T^{k'm'}_{\ell i} \in \left\{T^{km}_{\ell i}; k \in K'_{\ell i}, m \in M'^{k}_{\ell i}\right\}$ such that $T^{k'm'}_{\ell i} > T^{k''m''}_{\ell i}$. Q.E.D.

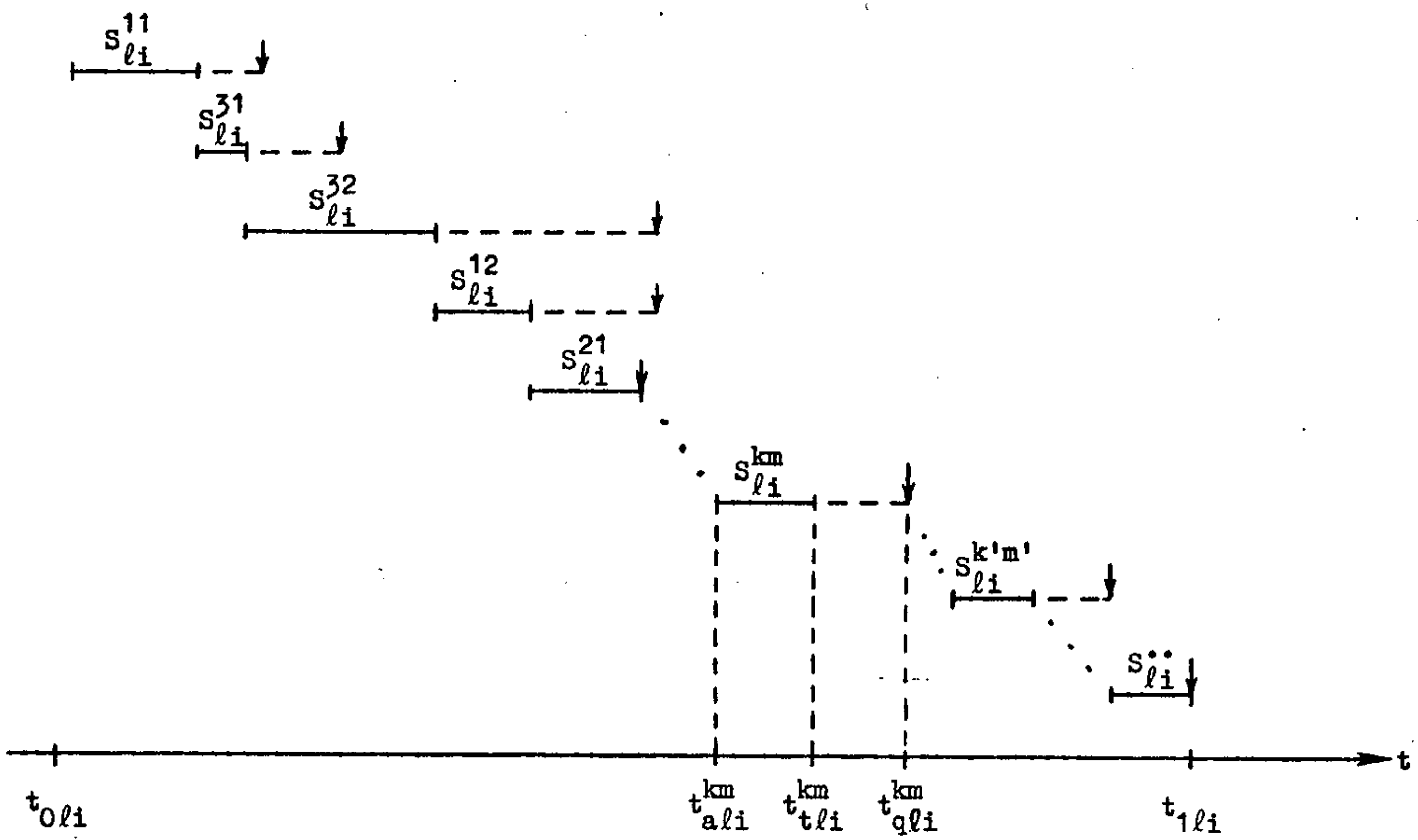

FIG. 7: A PARTIAL TSD GRAPH FOR SOME ROLE $r_{\ell i}$

Jaques [27] has also put forth a "one-rank distance" hypothesis or proposition regarding the hierarchical structure and vertical size of an organization based on his LOW estimators. It suggests that there exists a universal organization-rank system of seven ranks (strata) each spanning a certain LOW range. Any organization, even the largest corporations, should ideally have a role structure such that any two immediate superior-subordinate roles have LOW's that fall in the same relative position within two adjacent ranks.

This proposition may be elaborated on most simply by letting ΔL_r denote the length of the LOW range or interval $\Delta L_r = \{L : \underline{L}_r \leq L \leq \overline{L}_r\}$ of the r-th organizational rank where $\underline{L}_r = \overline{L}_{(r-1)}$. Jaques claims to have determined empirically that $\underline{L}_r$ = 15 min., 3 mos., 1 yr., 2 yrs., 5 yrs., 10 yrs., 20 yrs. for $r=1,\ldots 7$. The one-rank distance hypothesis may now be formulated as

$$(\hat{L}_{\ell i} - \underline{L}_r)/\Delta L_r = (\hat{L}_{(\ell-1)ij} - \underline{L}_{(r-1)})/\Delta L_{(r-1)} \text{ for all } i, \ell = r \text{ and } j \in I_{\ell i} \quad (3.4)$$

If the LOW estimate of some single-task $r_{\ell i}$ is $\hat{\hat{L}}_{\ell i}$, then this estimate replaces $\hat{L}_{\ell i}$ in eq.(3.4).

3.3 Critical Evaluation of the TSD Method

Jaques' TSD concepts are felt to be highly relevant to the hierarchical task relationships between organizational roles and represent something of a break-through in this area. Even his most severe critics acknowledge that he has made a significant contribution to the area of job analysis and work measurement. His LOW estimators based on the TSD concepts are, however, subject to some theoretical problems and certain practical limitations. On the basis of our own theoretical analyses and empirical observations, we have come to conclude that the following issues, which will be detailed subsequently, appear to be the most significant weaknesses of Jaques' LOW estimators:

1. The TSD method directly considers only one dimension of work, i.e., 'responsibility' or discretion and furthermore considers only the time element of discretion while explicitly excluding the element of "importance".
2. It does not take into account the proportion of total working time devoted to the different tasks with the frequent result that the LOW estimates may be determined by the TSD of some task(s) to which the role incumbent devotes a relatively insignificant proportion of his time.
3. The TSD method considers only final review points and does not explicitly take into account the frequency and "intensity" of intermediate sampling points.
4. Because of Jaques' extreme-value LOW estimation, these estimates suffer from some obvious practical limitations related to points #5, #6 and #7 below.
5. The TSD method is too sensitive to analysis errors.
6. Lacking any rule for deciding on the TSD-window $T_{\ell i}$, the analyst has to make his own subjective choice.
7. The decomposition of aggregate role content into individual tasks is not unique and therefore has some important LOW estimation implications.
8. LOW estimates may be unduly influenced by factors or constraints that are not under the control of the role incumbents and

their supervisors.

9. Jaques' LOW estimators $\hat{L}_{\ell i}$ and $\hat{\hat{L}}_{\ell i}$ appear to be unreasonably different.

3.3.1 Incompleteness

The most typical criticism of the TSD method lies in the great simplicity in which it perceives "work" and measures its level (eg.,[6,21,38]). Most traditional job evaluation schemes analyze a job along various dimensions which may be considered as subsets of three main dimensions or job characteristics, i.e.,

1) job requirements (formal education and on-the-job training as well as mental and physical efforts required of the incumbent),
2) responsibility (for the safeguarding of plants, equipment, material and for the supervision and safety of others), and
3) working conditions (characteristics of the physical work environment such as noise level, temperature, etc.).

The TSD method clearly takes none of these three job characteristics explicitly into account; however, a LOW estimate cannot be said to be independent of these and in particular the first two. In this connection, it may be mentioned that Jaques' somewhat inconsistent and inappropriate use of the word "responsibility" has caused some unjust criticism of his TSD method [6]. It is apparent from all of Jaques' writings that his more general (than the above job evaluation) use of this word incorporates all the job holder's psychological feelings of the size or worth of his job as determined by the time element of discretion.

During our field studies we did obtain evidence that a role incumbent's as well as his superior's perception about the size of the former's job and individual tasks is strongly influenced by the discretionary job content. Not only the time element of discretion was found to be a determining factor here, but also the "amount" of discretion particularly for discretion associated with the expenditure of organizational resources. To account for this, Crossman [16] has proposed that each individual $T_{\ell i}^{km}$ be weighted with the rate at which company resources are being deployed by $rI_{\ell i}$ while carrying out each individual task $S_{\ell i}^{km}$. This weighting sequence would also incorporate the fraction of time devoted to the various tasks, which is felt should very definitely be accounted for in the LOW estimates. This should be especially important for multi-task $r_{\ell i}$ for which $\hat{L}_{\ell i}$ may be determined by the TSD of a single task to which $rI_{\ell i}$ devotes only a small fraction of his time during the chosen interval $T_{\ell i}$ and/or $I_{\ell i}^{km}$. We have found this to occur quite commonly during our field studies. Thus, for example, the tasks S_{21}^{6}, S_{23}^{6} and S_{136}^{3} analyzed in appendix A accounted, respectively, for only about 5%, 4% and 1% of these role incumbents' working time during the given intervals $T_{\ell ..}$.

3.3.2 Final Reviews

The TSD method considers only final feedback sampling points (review points) for individual tasks, i.e., the latest time instants at which a role incumbent's continuous exercise of marginally substandard discretion may be detected by his immediate superior. The method does not take into account the frequencies and "intensities" of intermediate sampling points. Since these quantities are partially determined by a supervisor's confidence in the satisfactory exercise of discretion by his subordinate, which in turn is influenced by the subordinate's and his subsystems' true performance level (see also the above analysis of the general feedback monitoring process), it is felt that the intermediate sampling points should somehow be reflected in the LOW estimators.

It may, of course, be argued that a LOW estimate for some role does implicitly incorporate the intermediate supervisory feedback sampling frequencies. Our own empirical observations partly support the hypothesis that there is a direct relationship between the TSD's of various tasks and their intermediate sampling frequencies in the general sense that such sampling frequencies tend to increase with increasing TSD. This relationship does not appear to be entirely consistent, however, and our field studies have shown some evidence not presented here in support of the alternative hypothesis that this relationship may occasionally be an inverse one.

3.3.3 Error Sensitivity

Because of Jaques' extreme-value LOW estimation, the estimates obtained are highly sensitive to analysis errors. This applies to both single- and multi-task roles where the LOW estimates may be determined by the TSD of a single task or task sequence. For a role $r_{\ell i}$ whose true LOW is $L_{\ell i}$, the error $(L_{\ell i} - \hat{L}_{\ell i})$ is partly caused by the analyst obtaining incorrect information about allocation points and/or targeted completion times and review points. Quality review points may be particularly subject to errors since quality standards are frequently implicitly set and not easily measurable. Similarly, targeted completion points may be difficult to determine with any accuracy (eg., r_{3223} in appendix B) especially when (i) an operation does not have well defined terminal goals, (ii) a project is allocated in terms of sub-projects which may easily be overlooked by the analyst and (iii) a task is performed during an early subset of a wide TSD-window $T_{\ell i}$ since this may require $rI_{\ell i}$'s supervisor and $rI_{\ell i}$ himself to recollect what was done several months back.

Less sensitive to TSD measurement errors would be the following alternative LOW estimators:

$$\hat{L}^{\bullet}_{\ell i} = \frac{1}{K_{\ell i}} \sum_{k=1}^{K_{\ell i}} w^{k}_{\ell i} \bar{T}^{k}_{\ell i} \quad \text{and} \quad \hat{L}^{\bullet\bullet}_{\ell i} = \frac{1}{M_{\ell i}} \sum_{(k,m)} w^{km}_{\ell i} T^{km}_{\ell i}$$

where $M_{\ell i} = \sum_{k=1}^{K_{\ell i}} M^{k}_{\ell i}$, $\bar{T}^{k}_{\ell i} = \frac{1}{M^{k}_{\ell i}} \sum_{m=1}^{M^{k}_{\ell i}} T^{km}_{\ell i}$ and $\left\{w^{k}_{\ell i}\right\}$ and $\left\{w^{km}_{\ell i}\right\}$ are weighting sequences that incorporate such factors as resource deployment rates, fraction of time during $T_{\ell i}$ devoted to different tasks and intermediate feedback sampling frequencies. These estimators would also avoid the critical comments given in points #1, #2 and #3 of this section and are less affected by the nonuniqueness of role content decompositions than are Jaques' estimators. We are not, however, suggesting that the estimators $\hat{L}^{\bullet}_{\ell i}$ and $\hat{L}^{\bullet\bullet}_{\ell i}$, both applying to multi- and single-task $r_{\ell i}$, are necessarily "better" overall than Jaques'.

3.3.4 TSD-window

One of the major shortcomings of the TSD method lies perhaps in the lack of any proposed rule for choosing the TSD-window $T_{\ell i}$. Jaques does not as much as mention this as a problem. All he does is to state that, with reference to a case diagram, "the particular time-span pattern repeats itself" ([25],p.104) and furthermore "that when the pattern of work in a role begins to change...such that the time-span pattern is significantly affected, then managers begin to change the pattern of review in such a manner that the time-span bracket is retained unchanged" ([25],p.106). These statements, which are made with reference to his first proposed LOW estimators*, are not generally supported by our own findings and are also contradicted by Jaques' own data ([26], p. 59). Such time-span pattern repetitiveness may certainly apply to some roles. However, there does not seem to be any theoretical or empirical justification for assuming that this holds in general.

The choice of $T_{\ell i}$ is no lesser a problem facing a TSD analyst when applying the LOW estimation approach formalized above. Because of this extreme-value LOW estimation, the estimate $\hat{L}_{\ell i}$ is a never decreasing function of $T_{\ell i}$ with no well-defined $\hat{L}_{\ell i}(T_{\ell i})\max$ for most $r_{\ell i}$ as $T_{\ell i} \to \infty$. Thus, for example, it was found for r_{23} discussed in appendix A that $\hat{L}_{23} = 1$ month if $T_{23} = 2$ months and $\hat{L}_{23} = 3$ months if $T_{23} =$ $= 1$ year and there did not appear to be any reason to believe that $\hat{L}(T_{23} = 1 \text{ year}) = 3$ months was a well-defined asymptote. In general, however, it seems reasonable to assume that $\hat{L}_{\ell i}(T_{\ell i})\max \leqslant L_{(\ell+1)\min}$ where $L_{(\ell+1)\min}$ is some lower limit on the LOW of the role occupied by the superior of $rI_{\ell i}$. This $L_{(\ell+1)\min}$ may perhaps be considered to be the LOW performed at by $rI_{\ell i}$'s superior during his initial employment period for this supervisory role assuming he is barely qualified for it (see, eg.,[26], p.9). According to the one-rank distance hypothesis, we should, of course, ideally have that $\hat{L}_{\ell i}(T_{\ell i})\max \in \Delta L_{r=\ell}$.

Rather than choosing $T_{\ell i}$ arbitrarily, the following general cri-

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[*] In <u>Equitable Payment</u>, Jaques considers the (width of the) LOW bracket and defines it as being the time between the first and the fourth review points. He changed this approach in his <u>Time-Span Handbook</u> to the one we have been using in this paper. He claims that this latter approach, which was introduced in order to simplify the application of the TSD method, "does not significantly change the measurements obtained by means of the previous instrumentation" ([26],p.44). Theoretically, this statement is clearly incorrect (depending on what is "significant") and empirically our own data do not support this statement.

teria were used in the present study:

1) The upper endpoint $t_{1\ell i}$ coincides with the "point" at which the study was made where $t_{1\ell i}$ is approximately the same for all relevant ℓ and i.
2) $T_{\ell i} \gg \underline{L}_r$ for $r=\ell$,
3) For a given ℓ, $T_{\ell i}$ = const. for all i,
4) $T_{\ell i}$ increases with increasing ℓ,
5) $T_{\ell i}$ is chosen such that it does not barely cause the exclusion of some element(s) of $\{S^{km}_{\ell i}\}$ that would significantly increase the $L_{\ell i}$ estimate had it (they) been included in $\{S^{km}_{\ell i}\}$ (similar comments apply to the set of task sequences for single-task $r_{\ell i}$ for which $t^{km}_{q\ell i} > t^{km}_{t\ell i}$ for some $k \epsilon K_{\ell i}$ and $m \epsilon M^{k}_{\ell i}$), and
6) $T_{\ell i}$ is chosen such that the TSD data obtained are felt to be quite reliable (data reliability is likely to decrease with increasing $T_{\ell i}$).

3.3.5 Decomposition Nonuniqueness

The previously defined task decomposition of sec.2.3.3 is not unique in the sense that several analysts given the same detailed description of the role content or composite task $S_{\ell i}$ may not necessarily arrive at the same component tasks $S^{k}_{\ell i}$ and hence $S^{km}_{\ell i}$. This decomposition problem is clearly an important one from the TSD point of view and one which Jaques has failed to realize properly.*

Before elaborating on the problem we shall designate the above sets alternatively by means of the so-called set builder notation in

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*Jaques' concepts of part-task and sub-task (see [26],p.14) obviously does not solve this problem.

terms of which

$$S_{\ell i} = \{s_{\ell i} : C_{\ell i}\}$$

where the arbitrary element $s_{\ell i}$ has to satisfy some condition or property $C_{\ell i}$. The nonuniqueness of the task decomposition may then be attributed to the lack of sufficient precision for $C_{\ell i}$. Thus, according to Jaques, $C_{\ell i}$ simply requires that $s_{\ell i}$ (i) contain discretionary content w.r.t. quality and timing (progressive degree of completion) and (ii) have an ascertainable targeted completion point set by $rI_{\ell i}$'s immediate superior. There is no requirement as to the "amount" of discretion just as long as it can be established that $s_{\ell i}$ does in fact contain some discretionary content.

The condition $C_{\ell i}$ is clearly too general to prevent two persons, who are analyzing the same $r_{\ell i}$ and using the same TSD-window $T_{\ell i}$, from arriving at the sets (dropping the index sets $K_{\ell i}$, $K'_{\ell i}$, $M^k_{\ell i}$, $M'^k_{\ell i}$ for notational simplicity)

$$S_{\ell i} = \{S^k_{\ell i}\} = \{S^{km}_{\ell i}\} \quad \text{and} \quad S'_{\ell i} = \{S'^k_{\ell i}\} = \{S'^{km}_{\ell i}\}$$

where all the $S^k_{\ell i}$ and hence $S^{km}_{\ell i}$ may not be equal to the $S'^k_{\ell i}$ and $S'^{km}_{\ell i}$ even if it is assumed that $S_{\ell i} = S'_{\ell i}$ ($S_{\ell i} \subset S'_{\ell i}$ and $S'_{\ell i} \subset S_{\ell i}$). The underlying problem is the choice of the resolution level for the decomposition since we may have that $S^k_{\ell i}$ contains more than one element from $S'_{\ell i}$ for one or more $k \in K_{\ell i}$ and/or $S'^k_{\ell i}$ contains more than one element from $S_{\ell i}$ for one or more $k \in K'_{\ell i}$. However, even though this would result in the corresponding two TSD sets being unequal, i.e., $\{T^{km}_{\ell i}\} \neq \{T'^{km}_{\ell i}\}$, it does not necessarily follow that the resulting LOW estimates are different. There are in fact three important implications here, i.e.,

1) If both analysts identify $r_{\ell i}$ to be multi-task, then ideally

$\hat{L}_{\ell i} = \hat{L}'_{\ell i}$. This is clearly so since the element(s) in $S_{\ell i}$ accounting for $\hat{L}_{\ell i}$ is also contained in $S'_{\ell i}$ and the element(s) in $S'_{\ell i}$ whose TSD determines $\hat{L}'_{\ell i}$ is also contained in $S_{\ell i}$.

2) If one of the analysts identifies $r_{\ell i}$ to be single-task with $t^{km}_{q\ell i} > t^{km}_{t\ell i}$ for some $k \epsilon K_{\ell i}$ and $m \epsilon M^{k}_{\ell i}$ while the other analyst determines it to be multi-task, then $\hat{L}_{\ell i} \neq \hat{L}'_{\ell i}$ with probability 1. This follows from the above definition of the two LOW estimators.

3) Since there is no prescribed lower bound on the resolution level for the role content decomposition, (almost) any role may be considered to be multi-task. There are, however, some such indirect upper bounds due to different "task" allocation and review (and/or targeted completion) points. The term "almost" is used here since the further breakdown of some or all of the $S^{km}_{\ell i}$ may result in definite sequences of nonoverlapping tasks (i.e., $I^{km}_{\ell i} \cap I^{k'm'}_{\ell i} = \emptyset$) associated with certain simple repetitive manual operations.

As examples in support of the above nonuniqueness arguments consider the $r_{11j}(j=1,\ldots,12)$, $r_{13j}(j=1,\ldots,7)$, $r_{14j}(j=1,\ldots,5)$ analyzed in appendix A. Thus, for r_{145} we may consider that $S^{2}_{145} = \{S'^{1}_{145}, S'^{2}_{145}, S'^{3}_{145}, \ldots\}$ where S'^{1}_{145} = cleans office x, S'^{2}_{145} = cleans corridors, S'^{3}_{145} = cleans toilets and supplies paper,.... For $j=1,\ldots,6$, we may let $S^{1}_{11j} = \{S'^{1}_{11j}, S'^{2}_{11j}, S'^{3}_{11j}\}$ where S'^{1}_{11j} = operates weaving machines, S'^{2}_{11j} = rolls up woven fabric and S'^{3}_{11j} = removes rolls from machine take up. All of these S'^{k}_{1ij} were found to satisfy the conditions C_{1ij} (see also appendix A). Furthermore and as should be apparent from the analyses in the appendix, $I^{km}_{1ij} = I'^{k'm}_{1ij}$ for each of the given i,j,k and for all $k' \epsilon K^{k}_{1ij}$ and $m \epsilon M^{k}_{1ij}$; K^{k}_{1ij} being the index set corresponding to all $S^{k'}_{1ij} \epsilon S^{k}_{1ij}$ and $I'^{k'm}_{1ij}$ being the time interval between the allocation and targeted completion point for $S'^{k'm}_{1ij}$. Therefore, for the above i,j,k, $T^{km}_{1ij} = T^{k'm}_{1ij}$ for all $k' \epsilon K^{k}_{1ij}$ and $m \epsilon M^{k}_{1ij}$ and hence $\hat{L}_{1ij} = \hat{L}'_{1ij}$.

Consider now the decomposition of role content into component tasks at lower resolution levels than used in appendix A. Thus, for j=1,...,6, S^{2}_{11j} may be incorporated into S^{1}_{11j}, i.e., $S'^{1}_{11j} = \left\{S^{1}_{11j}, S^{2}_{11j}\right\}$ = operates weaving process. Similarly, S^{2}_{117} and S^{3}_{117}, S^{1}_{118} and S^{2}_{118}, S^{1}_{11j} and S^{2}_{11j} for j=9,...,12 may be aggregated into one task without violating conditions $C_{1..}$. These combinations of tasks are seen to maintain the given $\hat{L}_{11j} = \hat{L}'_{11j}$ for j=1,2 since r_{111} and r_{112} still remain multi-task and $T^{1m}_{11j} = T^{2m}_{11j} = T'^{1m}_{11j}$ for each $m \epsilon M^{1}_{11j} = M^{2}_{11j}$ and for j=1,2. However, as is apparent from the appendix, the roles r_{11j}(j=5,...,12) now clearly become single-task. Without having obtained these single-task LOW estimates we can only hypothesize as highly likely that $\hat{L}_{11j} \neq \hat{L}'_{11j}$ for these j.

Lacking a sufficiently precise condition $C_{\ell i}$ for uniquely decomposing $S_{\ell i}$ into a set of component tasks $\left\{S^{km}_{\ell i}\right\}$, $C_{\ell i}$ was modified in the present study to $C'_{\ell i}$, which, in addition to incorporating the above requirements of $C_{\ell i}$, imposes the following requirements on the members of $\left\{S^{km}_{\ell i}\right\}$:

1) As mentioned before, the $S^{km}_{\ell i}$ should be functionally distinct.
2) Related to #1 is the requirement that any member of $\left\{S^{km}_{\ell i}\right\}$ has to contain component elements that are more highly functionally interrelated than they are related to component elements of some other $\left\{S^{km}_{\ell i}\right\}$ member(s).
3) Each member of $\left\{S^{km}_{\ell i}\right\}$ should be at comparable resolution levels.
4) If the role content of $r_{\ell i}$ (or some aspects thereof) is compara-

ble to that of some other role $r_{\ell' i'}$, then the members of $\{S^{km}_{\ell i}\}$ (or some subset thereof) should be comparable to those of $\{S^{km}_{\ell' i'}\}$.

3.3.6 $\hat{L}_{\ell i}$ Constraints

It also appears that Jaques' LOW estimates for both multi- and single-task roles may be unduly influenced by various factors or constraints that are not under the direct control of the role incumbents and/or their supervisors. Certain standard and centralized company task allocation and review procedures are examples of factors that may strongly influence LOW estimates for different roles. Most of the tasks performed by the $rI_{2i}(i=1,3,4)$ are seen from appendix A to be subject to these types of constraints. However, in this case the constraints do not affect the tasks $S^6_{2i}(i=1,3,4)$ which determine the LOW estimates $\hat{L}_{2i}(i=1,3,4)$. For some of these tasks, the superintendent rI_3 indicated that he would have allocated longer TSD's had it not been for these constraints.

For most of the shopfloor roles analyzed in appendix A, the LOW estimates are directly influenced by the production capacities of the shops. Had the production capacities been larger or the product demand lower, the weaving and galvanizing processes might only have been operated during the day shift in which case we would have had that $\hat{L}_{11j} \gg$ $\gg 1$ day for $j = 2,5,7,9,10$ and $\hat{L}_{111} > 4$ days. This would be the case since the foreman rI_{21} would now consider the targeted completion instants for the tasks responsible for the given LOW estimates as being his scheduled completion times for the various production orders (see appendix A).

Such factors as those exemplified above may significantly affect LOW estimates and what seems to be unduly so in the sense that such factors may not markedly constrain level of work as estimated by some method other than the TSD one. In extreme cases, such factors may conceivably cause LOW estimates by the TSD method to be somewhat independent of the role incumbents' "true" performance level (or performance level measured along some scale other than the TSD one), their LOW capacities and their superiors' "expected" unconstrained review behavior.

3.3.7 $\hat{L}_{\ell i}$ vs. $\hat{\hat{L}}_{\ell i}$

A comparison between Jaques' LOW estimators $\hat{L}_{\ell i}$ and $\hat{\hat{L}}_{\ell i}$ defined in eqs.(3.2) and (3.3) warrants the following comments:

1) $\hat{L}_{\ell i}$ and $\hat{\hat{L}}_{\ell i}$, respectively, incorporate $t^{km}_{t\ell i}$ and $t^{km}_{q\ell i}$ under the assumption that $t^{km}_{t\ell i} \geqslant t^{km}_{q\ell i}$ for multi-task $r_{\ell i}$ and $t^{km}_{q\ell i} \geqslant t^{km}_{t\ell i}$ for single-task $r_{\ell i}$ and for all $k \epsilon K_{\ell i}$ and $m \epsilon M^{k}_{\ell i}$ (see eq.(3.1)). The latter assumption appears to be a reasonable one; however, the assumption regarding multi-task $r_{\ell i}$ seems less plausible and is not entirely supported by the findings of our own field studies.
2) $\hat{L}_{\ell i}$ and $\hat{\hat{L}}_{\ell i}$ appear to be too significantly different as compared to what may be a rather trivial difference between multi- and single-task $r_{\ell i}$. Whether $r_{\ell i}$ is single- or multi-task may simply depend on whether the sets $I^{km}_{\ell i}$ and $I^{k'm'}_{\ell i}$ for a single (k,m,k',m') are disjoint or not; the corresponding $\hat{\hat{L}}_{\ell i}$ and $\hat{L}_{\ell i}$ may, however, be considerably different.
3) This significant difference between the estimators $\hat{L}_{\ell i}$ and $\hat{\hat{L}}_{\ell i}$ may clearly limit the reliability of differential LOW comparisons, especially between the different i for a given ℓ.

3.3.8 Concluding Comments

Several points have been raised that have certain important implications for the validity of Jaques' LOW estimation based on the TSD concepts. Because of these theoretical limitations and practical problems, Jaques' LOW estimators are not felt to be entirely satisfactory and we would have certain reservations about recommending to a firm that such estimates be the sole base for establishing pay differentials. Nevertheless, we feel that such estimates have a definite utility as a management tool and that furthermore, the TSD concepts underlying LOW estimates relate to highly significant organizational system characteristics.

4. EMPIRICAL TSD RESULTS

4.1 Locale

The study was conducted in a number of industrial firms with most of our effort going into the TSD analyses in two of these firms. One of them, henceforth referred to as firm A, is a local conveyor belt and cyclone fence fabrication plant of a major U.S. steel company. This plant, which employs some 60 persons distributed over two shifts, produces cyclone fence (chainlink and rustake fence) and fabricates gates and various fittings as well as steel and stainless steel mesh conveyor belts. The operations of the plant are quite closely integrated into those of the company's local division.

The second firm (firm B), in which a more general TSD study was undertaken, is the Naval Air Rework Facility (NARF) of a U.S. Naval Air Station. Some 8000 civilian and 75 military personnel in over 130 trades and occupations handle the rework of naval aircraft such as the A-4 Skyhawk, A-3 Skywarrior, A7-A Corsair II, P-2 Neptune, P-3 Orion and of several types of missiles such as the Sparrow and the Shrike. The rework performed, which is mainly of the semi garage type rather than complete production line operations, includes repair, overhaul, conversion, betterment, progressive aircraft rework (PAR) and analytical rework. Some manufacturing of certain components and equipment is also performed.

4.2 Role Sample Studied

4.2.1 Firm A

Some 30 roles were selected on all the three organization levels of three branches containing the Fence & Gate Fabrication (weaving, galvanizing, gate fabrication and fittings), Warehouse & Shipping and Maintenance & Staff departments. A preliminary analysis of the roles in the Conveyor Belt Fabrication department was also conducted (see organization chart in Fig. 9, p. 90). The roles thus studied include supervisory and clerical personnel as well as direct and indirect labor.

4.2.2 Firm B

Only one section within each of the two branches of P-3 Rework (433) and Electrical & Missiles (422) belonging to the Airframes Division (53) and the Avionics Division (52), respectively, was included in the present study (see organization chart in Fig. 10, p. 91). LOW estimates were obtained for these branch and section heads as well as for the first-line supervisors of these sections and some of the shopfloor roles. The role sample analyzed thus constitutes about 5% of the total population of supervisory roles at and below the division level.

4.3 Data Acquisition Procedure

The procedure adopted for collecting the relevant TSD data in the present study followed quite generally that recommended by Jaques. Thus, the main technique used consisted of interviewing the role supervisor $rI_{\ell+1}$ when analyzing the work that he allocates to his subordinate role incumbent $rI_{\ell i}$. The information thus obtained was compared with that obtained by interviewing $rI_{\ell i}$ himself and in some instances his supervisor-once-removed, i.e., $rI_{\ell+1}$'s supervisor. Any discrepancy between these sets of data was resolved by bringing it to their attention during another set of interviews, settling on the final statement by $rI_{\ell+1}$, and by physically observing the actual situation when-

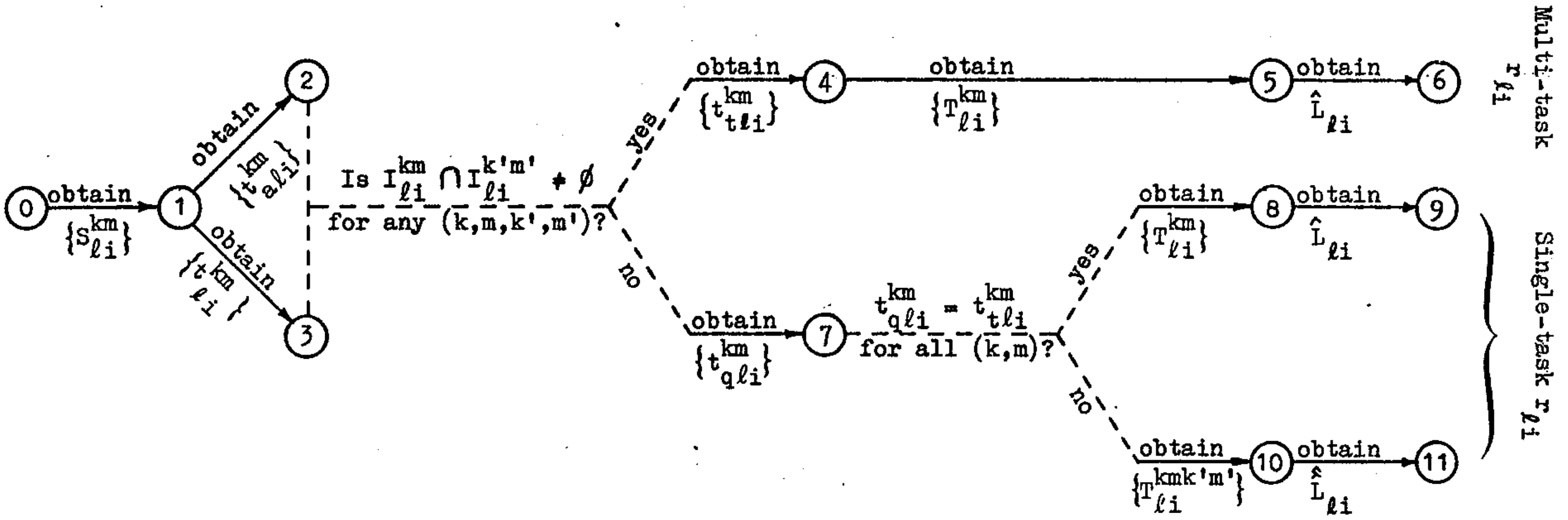


FIG. 8: FORMAL NETWORK DIAGRAM OF TSD DATA COLLECTION PROJECT FOR $r_{\ell i}$.

ever possible and feasible. The latter approach was used for shop-floor roles by the analyst spending some time observing the process operations and the flow of work from one process to another; for supervisory roles, this was accomplished by frequent sampling of work in progress and by attending general work review and allocation meetings for supervisory personnel.

The TSD data required for obtaining $\hat{L}_{\ell i}$ were formally acquired through the step procedure outlined in Fig. 8 on the preceeding page.

4.4 Discussion of Field Results

4.4.1 Results from Firm A

A detailed account of the TSD analysis for most of the roles studied is given in appendix A. The LOW estimates are also summarized in Table 1 below.

These results do indicate that the TSD method makes a clear differentiation between the level of work for roles on different organizational levels. The LOW differences between the level-2 roles $r_{2i}(i=1,3,4)$ and the level-3 role of superintendent (r_3) do appear, however, to be rather small. According to the one-rank distance hypothesis, we should ideally have that $\hat{L}_3 \approx 1$ year assuming the estimates $\hat{L}_{2i}(i=1,3,4)$ are appropriate. Rather than concluding that the organizational role structure is suboptimal between the levels 2 and 3, it is felt that $\hat{L}_3 = 8$ months is an underestimate of the true L_3. Because of personnel changes occurring during the period of our field studies, we were unable to revise this estimate. The LOW differentials between level-1 and -2 roles, however, appear to be quite "appropriate".

As is seen from Fig. 11a below, there exists a significant positive correlation between actual income and the LOW estimates obtained. These income figures are based on "organization time" rather than real time, i.e., 1 month = 4.4 weeks = 22 days; the income scale in \$ per unit organization time is left unspecified to comply with company wishes. Based on these data the value of the standard correlation coefficient estimator of $\hat{L}$ and income was found to be 0.96.

The company does maintain a job-class scheme for supervisory personnel based on a scale from 0 to 20. The plant's superintendent rI_3 also ranked all the shopfloor and clerical role incumbents along this scale according to what he felt were the levels of work performed. No special compensation was given for swing-shift work as such. The plot of these role rankings versus LOW estimates as shown in Fig. 11b indicates a clear linear relationship between these two sets of data. The corresponding estimate for the correlation coefficient was found to be 0.93.

In spite of these highly significant correlations between the LOW estimates and actual pay rates and role rankings, the various supervisors, when presented with these data, did express grave misgivings about employing the LOW estimates obtained for designing their subordinates' wage structure. These supervisors had been given a fairly general introduction to the TSD method and did acknowledge that the TSD concepts were important. However, their main objection was that this method of evaluating level of work is too simplistic by itself and that task "importance" ought to be incorporated into the LOW estimation.

All the roles analyzed are seen to be multi-task. Some roles are clearly multi-task in that all tasks are intermittent whereas others, in particular the shopfloor roles $r_{13j}(j=2,3)$, are barely multi-task as they contain mainly continuous type tasks.

4.4.2 Results from Firm B

The LOW estimates obtained are given in Figs. 12 and 13 (two left-hand side columns). A very general account of the TSD analysis for our role sample is given in appendix B. No detailed TSD analyses were made in this case. Rather than analyzing each role in terms of its individual tasks and attempting to acquire their TSD values as was done in the case of firm A, the present study was primarily aimed at obtaining only LOW estimates for the purpose of making some structural inferences based on the one-rank distance hypothesis.

The data clearly show that the LOW estimates $\hat{L}_{\ell i}$ are differentially distributed within the parts of the organization studied. In particular, $\hat{L}_{\ell i}$ increases with increasing ℓ; however, some of the differentials do not appear to be optimal in the sense of satisfying the one-rank distance criterion. This observation is most directly made from Figs. 12 and 13. These charts, which we are referring to as organization-rank charts, depict the organization charts superimposed on a "rank chart" for which the horizontal lines mark the end points $\underline{L}_r$ and $\overline{L}_r$ of the LOW intervals ΔL_r of the ranks $r = 1,\ldots,4$. The organizational role "boxes" $r_{\ell i\ldots}$ are placed such that the vertical position of their centers correspond approximately to their LOW estimates $\hat{L}_{\ell i\ldots}$ in relation to the $\underline{L}_r$ and $\overline{L}_r$.

In particular, it is seen that $\hat{L}_{23352}$ $(\equiv\hat{L}_{22}) = \hat{L}_{23354}$ $(\equiv\hat{L}_{24}) \notin \Delta L_2$ so that eq. (3.4) is not satisfied for $i = 2,4$ and for all $j \in I_{2i}$. In fact, by appropriate substitutions into eq. (3.4), it is found that the value of the right-hand side ranges from about 0 to 0.1 for different j-values whereas the left-hand side is approximately equal to -0.1 for $i = 2,4$. For $\ell = 3$ and the roles r_{3335} ($\equiv r_{31}$) and $r_{2335\ell}$ ($\equiv r_{21j}$) ($j,\ell=1,..,4$), it is seen that the value of the right-hand side of eq. (3.4) is equal to 0 or -0.1 while its left-hand side is equal to 0.2. Similarly, the one-rank distance criterion is not entirely met for the roles r_{433} and r_{3335}.

The hierarchical role structure of branch 422, however, appears to be quite appropriate in the sense that the estimated LOW differentials do not significantly violate eq. (3.4) with the exception of roles r_{422} and r_{3223} (see Fig. 12). These two roles are separated in LOW by more than one-rank distance in Jaques' terminology. However, there are no immediate superior-subordinate roles whose LOW estimates fall entirely within the same rank as was found to be the case for branch 433 (r_{23352}, r_{23354} and their subordinate shopfloor roles).

All in all, our data do not uncover any highly significant suboptimalities in the role structure of the two organizational branches studied but for the couple of exceptions mentioned above. It is not felt, however, that these exceptions would be identified by any criterion of structural "goodness" other than the one-rank distance one. We certainly found no evidence that "considerable bypassing of the immediate manager (rI_{23352} and rI_{23354}) occurs" ([27], p. 16) or that "something less than a full-scale managerial relationship exists between B (rI_{23352} and rI_{23354}) and C (the subordinates of the two rI.....)" ([27], p.17).

4.5 Difficulties Encountered in Obtaining TSD Data

In addition to the problems discussed above under our evaluation of the TSD method such as the choice of task set for a role, the following were some of the difficulties met with during the study:

a) Supervisors often tend to view their subordinates' work in more general terms and are not accustomed to consciously looking at work in such detail as the TSD analyst has to. This was especially the case when superior-subordinate relationships were very well established. This made it often difficult and time-consuming for the analyst to identify the individual tasks and the required TSD data.

b) Supervisors also tend to focus their attention on those subordinates' tasks that they consider to be the most "important" ones and which are not always those that the analyst is most interested in for obtaining $\hat{L}_{\ell i}$. The analyst often had to make repeated attempts at trying to make these supervisors concentrate on tasks they considered to be relatively minor.

c) A role incumbent may have more than one immediate superior, each being in charge of different areas of the incumbent's work. This made it difficult sometimes for the analyst to decide which superior was supervising which tasks.

d) The prescribed limits of discretion were often found to be rather difficult to establish. This was especially the case with these limits or standards for quality, which are almost always implicitly set as a matter of intuitive understanding between the superior and his subordinate. The almost inevitable result of this was that the quality review instants were often difficult to determine for some tasks. Fortunately for the analyst, all roles studied and reported here were found to be multi-task so that the above problem was strictly speaking not encountered in the estimation of LOW.

e) The targeted completion points were sometimes difficult to ascertain with any accuracy. This problem seemed to arise particularly in connection with projects whose (i) terminal goal was not clearly defined, (ii) priority assignment was relatively low and (iii) resource deployment rate was low.

5. CONCLUDING REMARKS AND PROJECTED FUTURE RESEARCH

While our development of a general OPFCS model has been far from completed, nevertheless, we feel that its present state may yield significant insight into the structure and general behavior of organizations and offer a good point of departure for further research into the model characteristics. This model, which is sufficiently general to fit most types of organizations, falls within the domain of what we have termed organizational cybernetics. Consequently, one would ultimately hope that the powerful and highly general quantitative techniques of control system theory may be applied towards the analysis and design of total organizations and their subsystems. This would of course require the extension of control system theory into multilevel hierarchical systems as it is at present essentially limited to singlelevel control systems.

The TSD concepts, which we have attempted to formulate systematically and mathematically, are clearly important characteristics of the model and we feel that Jaques' work has made a significant contribution to any theory of organizations. However, Jaques' LOW estimators based on the TSD ideas are not felt to be altogether satisfactory because of various theoretical limitations and practical difficulties; this in spite of the fact that our own data and that of other researchers have indicated a fairly close correspondence between TSD based LOW estimates and more traditional indicators of LOW. Although we have raised certain important questions pertaining to the validity of LOW estimation based on the TSD concepts, nevertheless, it is felt that such estimates ought to be a valuable tool for any enlightened management. In particular, the one-rank distance hypothesis would appear to be a potential aid in diagnosing possible inappropriate hierarchical role structures of a given organization.

As regards the LOW estimation by means of the TSD concepts, our future research objectives are to

(i) make certain well-defined probabilistic statements about the LOW estimators such as their precision or reliability;

(ii) make statistical comparisons between these and some alternative LOW estimators such as those on p. 69;

(iii) establish a more objective way of determining the "appropriate" TSD-window width $T_{\ell i}$; and

(iv) determine the degree of influence on the $T_{\ell i}^{km}$ by factors such as control system feedback sampling frequencies and resource-deployment rates.

In addition to the data we have presently obtained, these statistical problems will require the collection of a considerable amount of time-series data for individual tasks across roles in order to determine the forms of the requisite probability density functions and to estimate the relevant parameters. Based on our preliminary data of relative frequency histograms for the $T_{\ell i}^{km}$ of any given task $S_{\ell i}^{k}$, it would appear that generalized beta distributions are appropriate. However, this remains to be further investigated.

For the OPFCS model as a whole, our current research plan calls for investigations into the

(i) supervisory sampling behavior as reflected by the sampled-data nature of our model's informational feedback;

(ii) cognitive process of adaptation and fast-time internal modelling; and

(iii) mathematical modelling and identification of system dynamics.

For the last of these research objectives it would obviously be most convenient to be able to assume that the various system elements are linear and time-invariant. A weaker assumption and one which our admittedly very incomplete data indicate may not be unreasonable, is to consider the different planning and control subsystems as being quasi-linear (and quasi-time-invariant) with not "too" significant remnant terms. By means of such quasi-linearization, which was first introduced by Tustin [45] for modelling the human control function in compensatory tracking, the transfer characteristics of the linear and time-invariant portion of non-linear and time-variant organizational planning and control systems (remnant terms account for the non-linear and time-variant portions of these systems) may be formulated in terms of impulse response functions in the time domain or transfer functions in the complex-frequency domain. The systems' dynamics would then be formulated mathematically in the form of matrix convolution (integral and/or sum) transformations in the time domain and matrix products in the frequency domain. Such matrix rather than scalar operations would be the result of our consideration that the various systems are generally multivariate.

We plan to test the feasibility of this approach in two or more ongoing organizations. Once a mathematical model of the systems' dynamics has been developed, system identification or parameter estimation will be made on the basis of real data from these organizations. Furthermore, the remnant terms will be evaluated since the utility of quasi-linearization depends on the relative significance of the remnants.

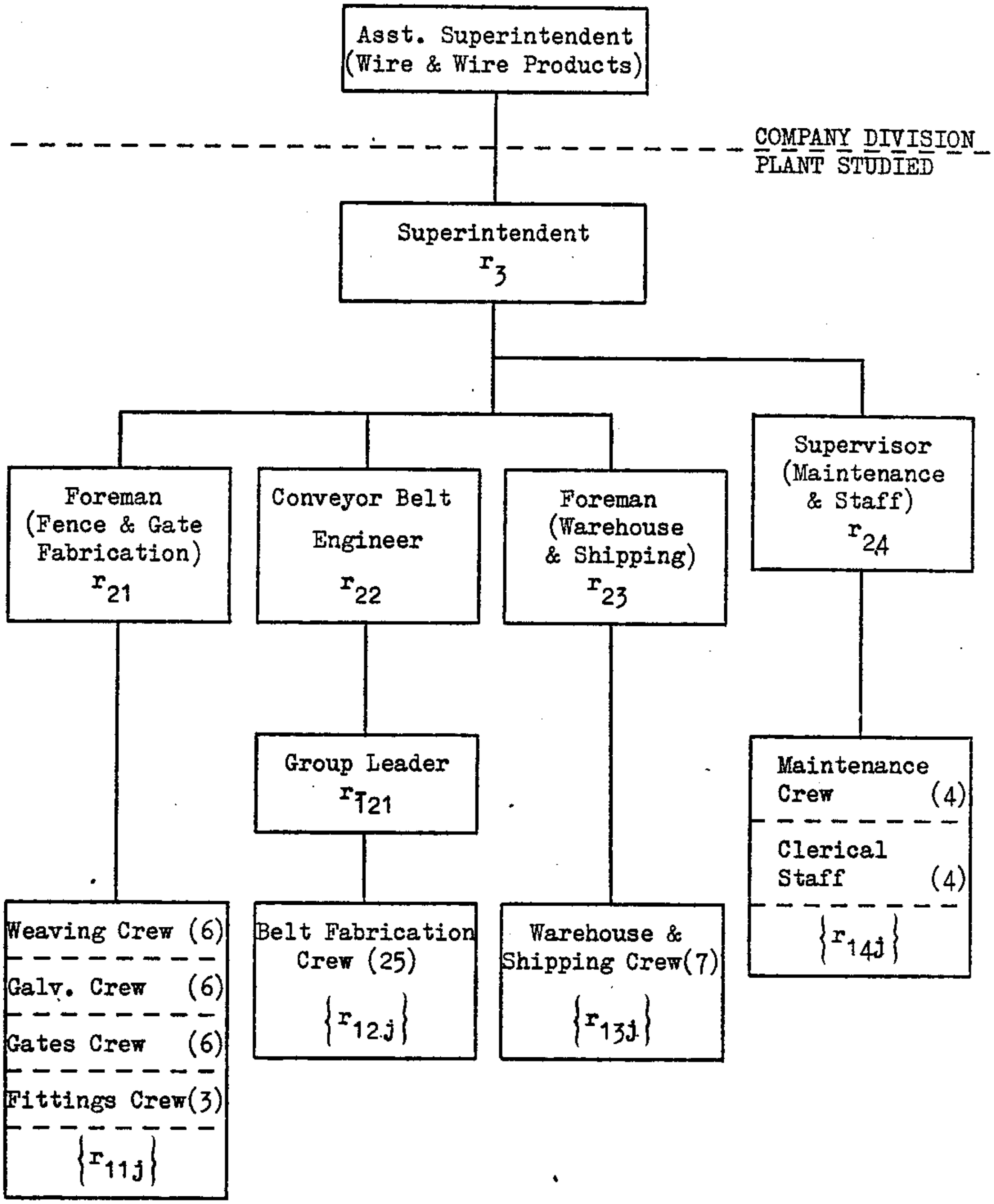


FIG. 9 : ORGANIZATION CHART OF CYCLONE FENCE AND CONVEYOR BELT FABRICATION PLANT

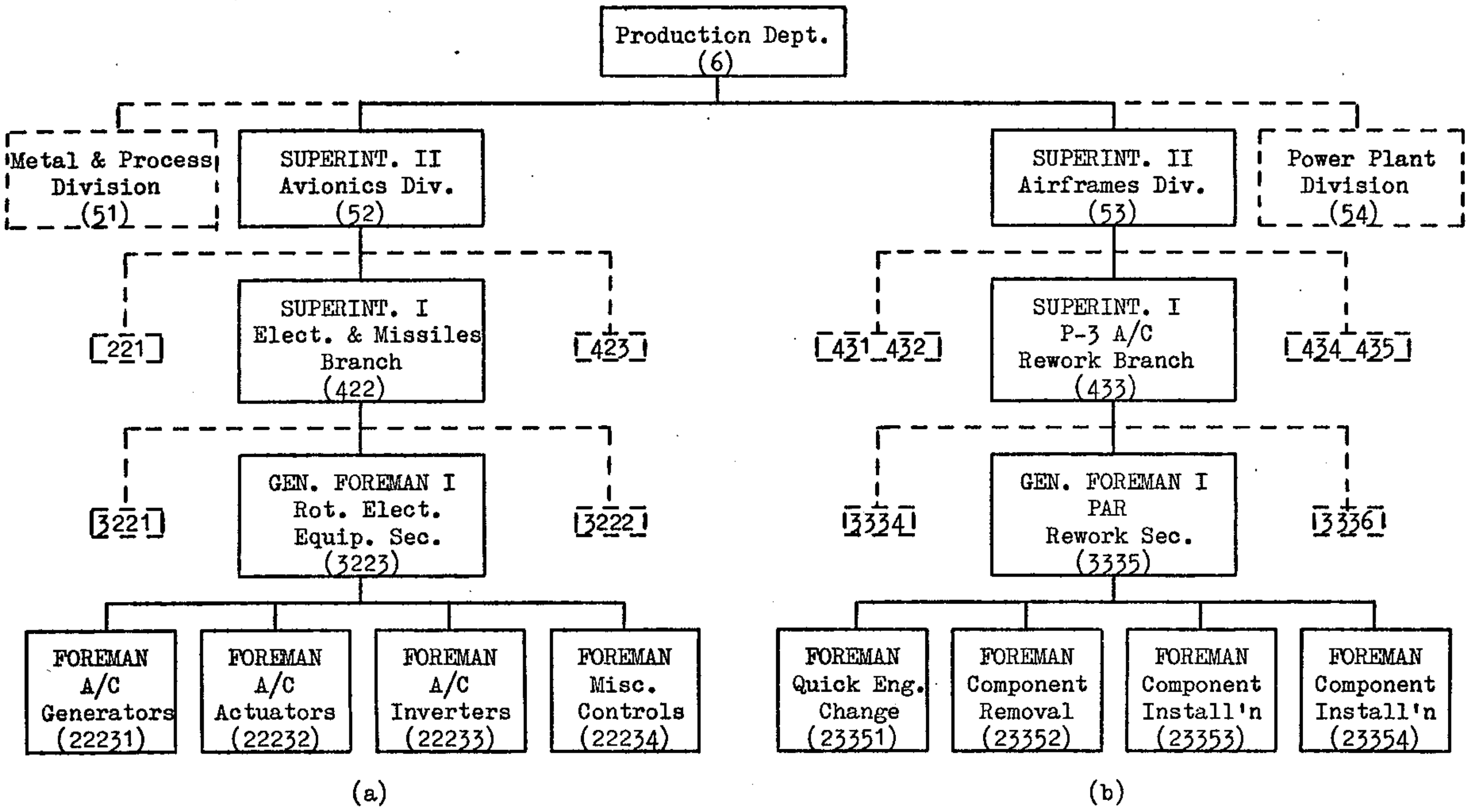


Fig. 10. ORGANIZATION CHART OF NARF. DIVISION OF AVIONICS (a) AND AIRFRAMES (b). (Solid parts indicate areas where TSD analyses were made.)

ROLES ANALYZED		LOW Estimates $\hat{L}_{\cdots}$
Role Identification	Role Titles	
r_3	Superintendent	8 months
r_{21}	Foreman (Fence & Gate Fabrication)	3 months
r_{111}	Mechanic	4 days
r_{112}	Machine Operator (Chainlink m/c, day shift)	1 day
r_{11j}(j=3,4)	Machine Operator (Chainlink m/c, swing shift)	1 day
r_{115}	Machine Operator (Rustake m/c, day shift)	1 day
r_{116}	Machine Operator (Rustake m/c, swing shift)	1 day
r_{117}	Head Galvanizer (day shift)	1 day
r_{118}	Head Galvanizer (swing shift)	1 day
r_{11j}(j=9,10)	Galvanizer (day shift)	1 day
r_{11j}(j=11,12)	Galvanizer (swing shift)	1 day
r_{23}	Foreman (Warehouse & Shipping)	3 months
r_{131}	Shipper	1 day
r_{13j}(j=2,3)	Loader/Unloader (day shift)	$\frac{1}{2}$ day
r_{13j}(j=4,5)	Loader (swing shift)	1 day
r_{136}	Storeroomkeeper	2 days
r_{137}	Shipping Clerk	1 day
r_{24}	Supervisor (Maintenance & Staff)	4 months
r_{14j}(j=1,2,3)	Maintenance Mechanic (day shift)	1 day
r_{144}	Maintenance Mechanic (swing shift)	2 days
r_{145}	Janitor	$7\frac{1}{2}$ hours
r_{146}	Layout Draftsman	2 weeks

TABLE 1: SUMMARY OF LOW RESULTS FROM FIRM A

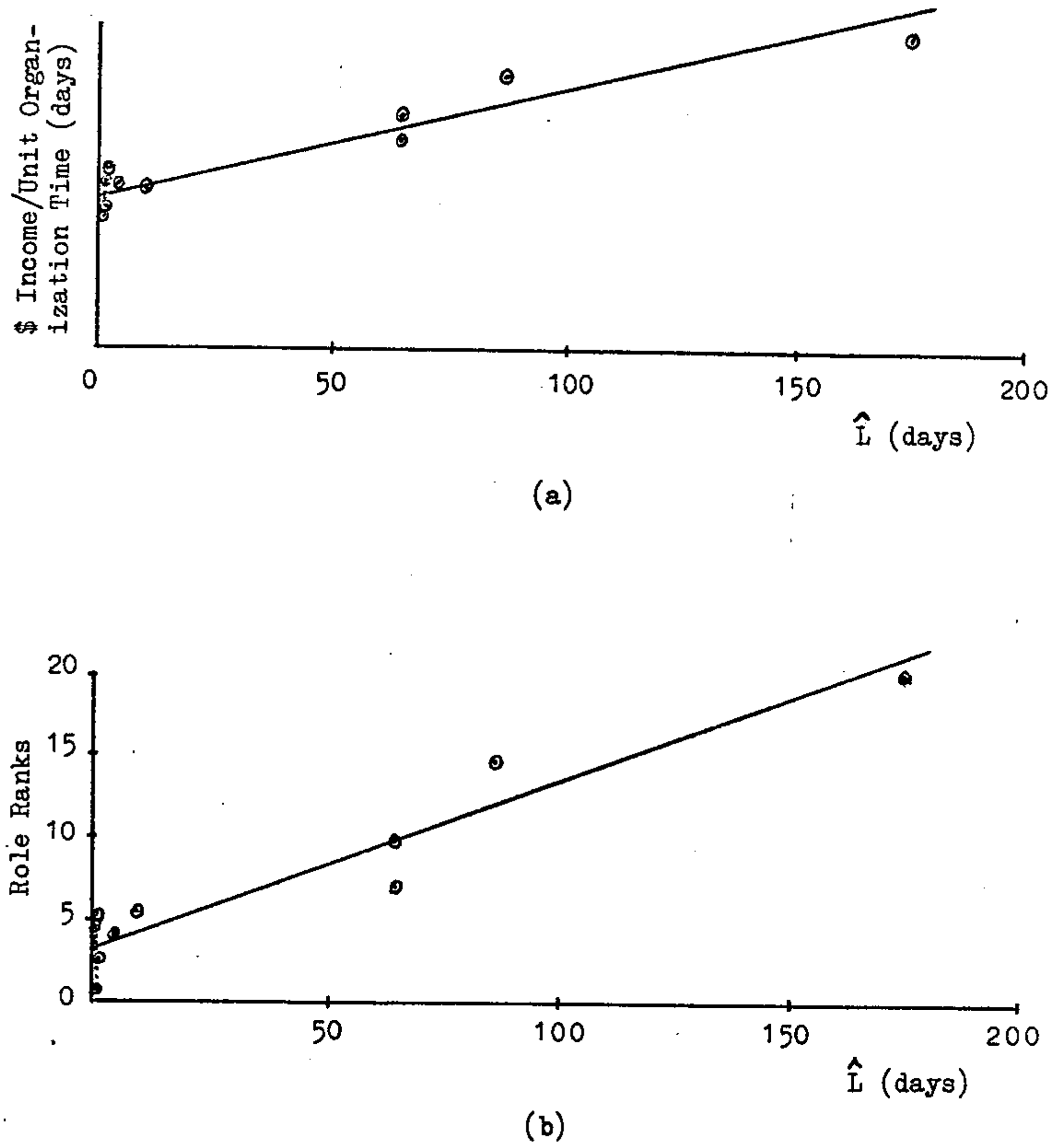


FIG.11: DAILY INCOME (a) AND ROLE RANKS (b) VERSUS LOW ESTIMATES (the ordinates of the points in (a) are left unstated by company request; the vertical scale is linear).

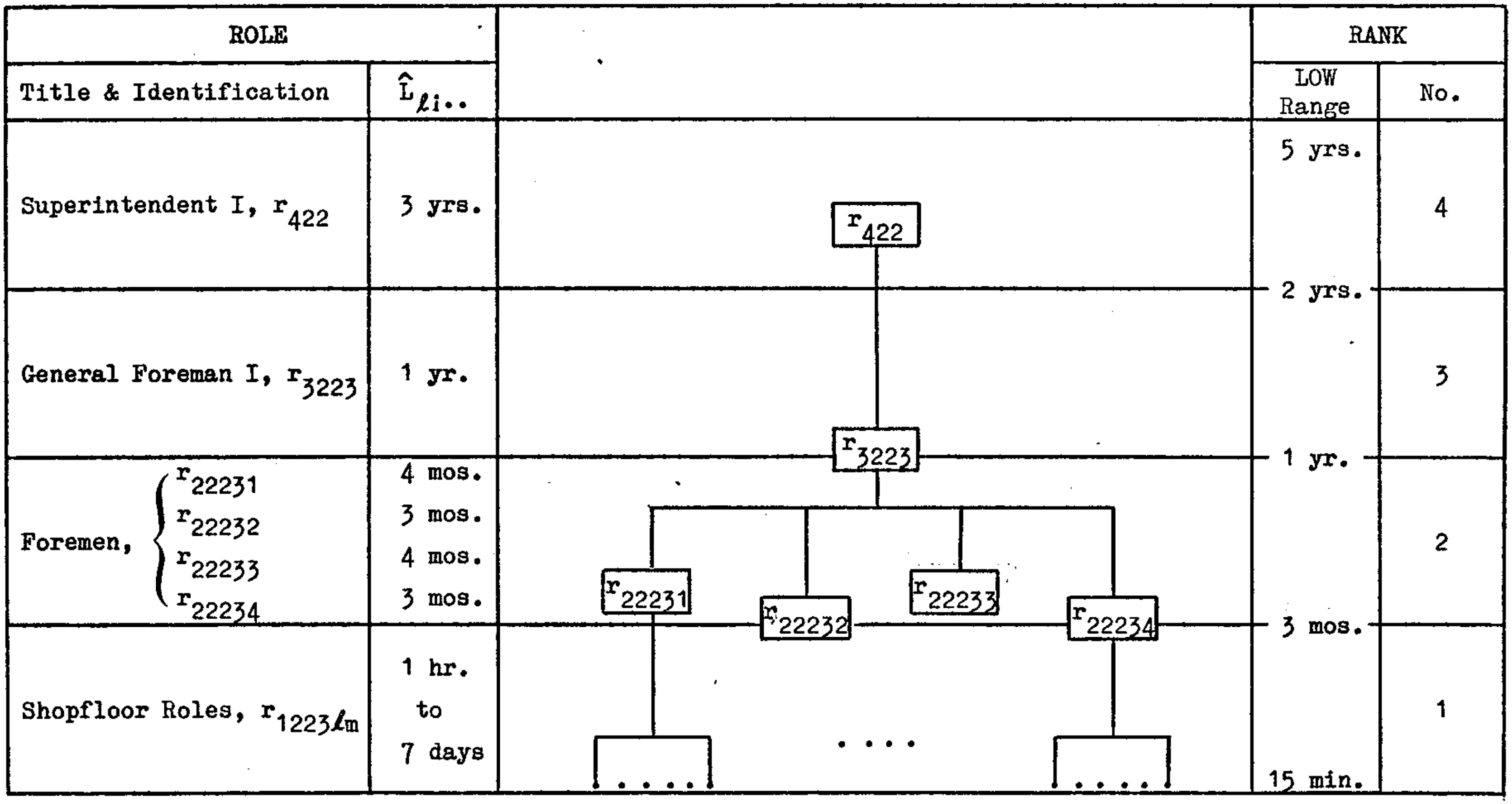
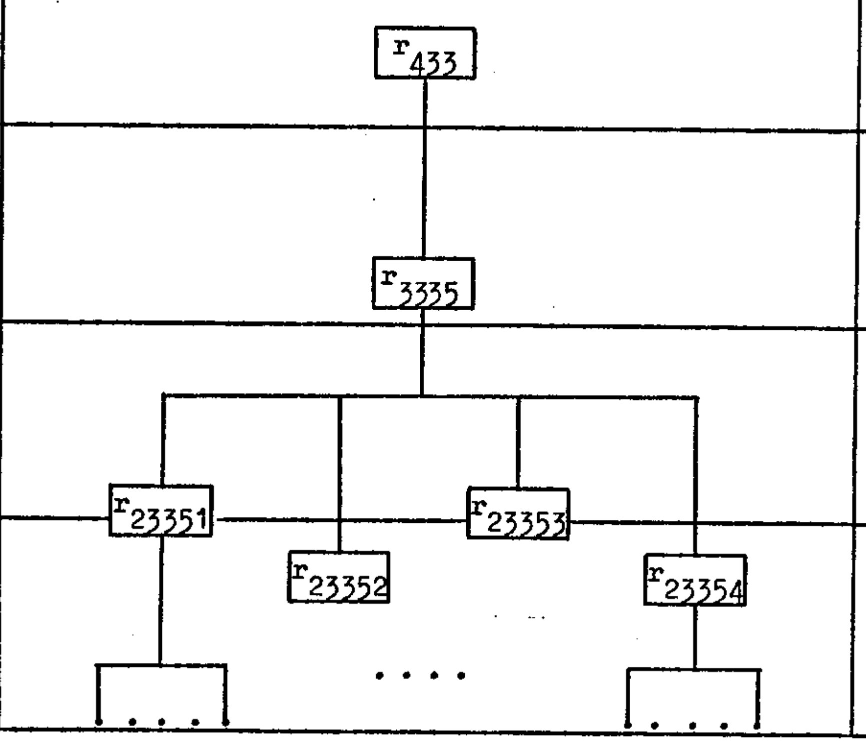


FIG. 12: ORGANIZATION-RANK CHART FOR PART OF BRANCH 422.



ROLE		RANK	
Title & Identification	$\hat{L}_{li..}$	LOW Range	No.
Superintendent I, r_{433}	3 yrs.	5 yrs. 2 yrs.	4
General Foreman I, r_{3335}	14 mos.	1 yr.	3
Foremen, $\left\{\begin{array}{l} r_{23351} \\ r_{23352} \\ r_{23353} \\ r_{23354} \end{array}\right.$	3 mos. 2 mos. 3 mos. 2 mos.	3 mos.	2
Shopfloor Roles, r_{1335lm}	1 hr. to 5 days	15 min.	1

FIG. 13: ORGANIZATION-RANK CHART FOR PART OF BRANCH 433.

Kvålseth

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